Fecal Bacteria and General Standard Total Maximum Daily Load Development for Back Creek

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EXECUTIVE SUMMARY

Background and Applicable Standards

Back Creek was placed on the Commonwealth of Virginia's 1996 303(d) TMDL Priority List because of violations of the fecal coliform bacteria water quality standard and the General Standard (benthic). The focus of this TMDL is on the fecal coliform and benthic impairments in Back Creek. Based on exceedances of the standard recorded at Virginia Department of Environmental Quality (VADEQ) monitoring stations, the stream does not support primary contact recreation (e.g., swimming, wading, and fishing). The new applicable state standard (Virginia Water Quality Standard 9 VAC 25-260-170) specifies that the number of fecal coliform bacteria shall not exceed a maximum allowable level of 400 colony-forming units (cfu) per 100 milliliters (ml). Alternatively, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 200-cfu/100 ml. A review of available monitoring data for the watershed indicated that fecal coliform bacteria were consistently elevated above the 400-cfu/100 ml standard. EPA directed that the state develop a water quality standard for E. coli bacteria to eventually replace the fecal coliform standard. This new standard specifies that the number of E. coli bacteria shall not exceed a maximum allowable level of 235-cfu /100 ml (Virginia Water Quality Standard 9 VAC 25-260-170). In addition, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 126-cfu/100 ml.

The General Standard is implemented by VADEQ through application of the Rapid Bioassessment Protocol II (RBP). Using the RBP, the health of the benthic macro-invertebrate community is typically assessed through measurement of 8 biometrics that evaluate different aspects of the community's overall health. Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level. Each biometric measured at a target station is compared to the same biometric measured at a reference (non-impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.*, non-impaired, moderately impaired, or severely impaired). Using this methodology, Back Creek was rated as moderately impaired.

TMDL Endpoint and Water Quality Assessment

Fecal Coliform

Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include: wildlife, grazing livestock, land application of manure, land application of biosolids, urban/suburban runoff, failed and malfunctioning septic systems, and uncontrolled discharges (straight pipes, dairy parlor waste, etc.). There are four Virginia Pollutant Discharge Elimination System (VPDES) permitted dischargers in the Back Creek watershed. Two are single-family wastewater permits. One is a confined animal feedlot permit with no discharge permit, and one is an industrial stormwater discharge permit not permitted for fecal coliform discharge. The single-family wastewater permits are small (<1,000 g/day) and are expected to meet the 126-cfu/100 ml standard.

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* standard. For this TMDL development, the in-stream *E. coli* target was a geometric mean not exceeding 126-cfu/100 ml and a single sample maximum of 235-cfu/100 ml. A translator developed by VADEQ was used to convert fecal coliform values to *E. coli* values.

General Standard (benthic):

TMDLs must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not but, generally do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (EPA, 2000) was used to systematically identify the most probable stressor(s) for Back Creek. A list of candidate causes was developed from published literature and VADEQ staff input. Chemical and physical monitoring data from ambient monitoring station 9-BCK009.47 provided evidence to support or eliminate potential stressors. Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). Landuse data as well as a visual assessment of conditions along the stream provided additional information to eliminate or support candidate stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity, temperature and organic matter.

The results of the stressor analysis for Back Creek were divided into three categories:

> **Non-Stressor**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.
>
> **Possible Stressor**: Those stressors with data indicating possible links, but inconclusive data were considered to be possible stressors.
>
> **Most Probable Stressor**: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

The results indicate that sediment is the Most Probable Stressor. Therefore, it is the most practical pollutant for TMDL development because it is interconnected with other possible stressors, such as organic matter and nutrient enrichment. For example, limiting livestock access to streams allows for streambank vegetation regrowth and reduces inputs of organic matter (manure) nutrients. Total phosphorus is typically bound to soil particles and enters the aquatic environment by the transport of sediment from the land. Stream buffers can reduce overland flow velocities and decrease the amount of sediment and sediment bound nutrients that reach the stream.

Sediment is delivered to the Back Creek watershed through surface runoff (rural and urban areas), streambank erosion, point sources, and natural erosive processes. The sediment process is a natural and continual process that is often accelerated by human activity. During runoff events (natural rainfall or irrigation), sediment is transported to streams from land areas (*e.g.,* agricultural fields, lawns, forest, etc.). Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Agricultural management activities such as overgrazing, (particularly on steep slopes), high tillage operations, livestock concentrations, (*e.g.*, along stream edge, uncontrolled access to streams, etc.), forest harvesting, and construction (roads, buildings, etc.) accelerate erosion at varying degrees. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events.

An increase in impervious land without appropriate stormwater control increases runoff volume and peaks, which leads to greater potential for channel erosion. It has been well documented that livestock with access to streams can significantly alter physical dimensions of streams through trampling and shearing (Armour, et al., 1991; Clary and Webster, 1990; Kaufman and Kruger, 1984). Increasing the bank full width decreases stream depth, increases sediment, and adversely affects aquatic habitat (USDI, 1998).

Fine sediments are included in total suspended solids (TSS) loads that are permitted for wastewater, industrial stormwater and construction stormwater discharge. There are two small single-family wastewater discharge permits and one industrial stormwater discharge permit located within the watershed.

Water Quality Modeling

Fecal Coliform

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and perform TMDL allocations. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. Due to the lack of continuous streamflow data for Back Creek, the paired watershed approach, with additional refinement using instantaneous flow measurements was used to calibrate the HSPF model. Through this approach, the HSPF model is calibrated using data from a hydrologically similar watershed, where continuous stream flow is available. The Upper Tinker Creek watershed was compared to the Back Creek watershed and chosen as an appropriate watershed for a paired-watershed calibration. The hydrologic comparison of the two watersheds was established by examining the landuse distribution, total drainage area, channel and watershed characteristics, and hydrologic soil group. The HSPF input parameters for the Upper Tinker Creek watershed were used as base input parameters when calibrating Back Creek with the flow values from USGS Stations #03171350 (Back Creek at Route 100, near Highland, VA), #03171400 (Neck Creek at Route 617 near Belspring, VA), and #03171405 (Back Creek At Route 600, near Parrot, VA) over the periods 1982 through 1984 and 2002 through 2003. The calibrated parameters from the model (*e.g.*, lower zone storage), in conjunction with physically derived parameters (*e.g.*, land slope and slope length) specific to Back Creek, are then used as initial representation of the watershed. This representation was then refined through calibration to instantaneous flow measurements collected for Back Creek primarily during base-flow conditions. The representative flow period used for hydrologic calibration covered the period October 1986 through September 1991. For purposes of modeling watershed inputs to in-stream water quality, the Back Creek drainage area was divided into five subwatersheds. The water quality calibration and validation were conducted using monitored data collected at VADEQ monitoring stations between October 1993 and September 2002. Modeled coliform levels matched observed levels during a variety of flow conditions, indicating that the model was well calibrated.

General Standard (benthic) - Sediment

There is no existing in-stream criteria for sediment in Virginia; therefore, a reference watershed approach was used to define allowable TMDL loading rates in the Back Creek watershed. This approach pairs two watersheds: one that is supportive of its designated use(s) and one whose streams are impaired. The Toms Creek watershed was selected as the TMDL reference for Back Creek. The TMDL sediment load was defined as the modeled sediment load for existing conditions from the non-impaired Toms Creek watershed, area-adjusted to the Back Creek watershed. The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was used for comparative modeling for both Back Creek and Toms Creek. Sufficient flow rate data was not available within Back Creek or from a nearby watershed for hydrologic calibration. Since the model was originally developed for use in ungaged watersheds, the model was used with recommended model parameters for the landuses and conditions found in the two watersheds.

Existing Conditions

Fecal Coliform

Wildlife populations and ranges, biosolids application rates and practices, rate of failure, location, and number of septic systems, domestic pet populations, numbers of cattle and other livestock, and information on livestock and manure management practices for the Back Creek watershed were used to calculate fecal coliform loads from land-based nonpoint sources in the watershed. The estimated fecal coliform production and accumulation rates from these sources were calculated for the watershed and incorporated into the model. To accommodate the structure of the model, calculation of the fecal coliform accumulation and source contributions on a monthly basis accounted for seasonal variation in watershed activities such as wildlife feeding patterns and land application of manure. Also, represented in the model were direct nonpoint sources of uncontrolled discharges, direct deposition by wildlife, and direct deposition by livestock.

Contributions from all of these sources were updated to 2003 conditions to establish existing conditions for the watershed. All runs were made using a representative precipitation record covering the period of October 1986 to September 1991. Under existing conditions (2003), the HSPF model provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the watershed.

General Standard (benthic) - Sediment

The benthic TMDL for Back Creek was developed using sediment as the primary stressor and the Toms Creek watershed as the reference watershed. The Toms Creek watershed is smaller than the Back Creek watershed. Landuse categories in the Toms Creek watershed were increased by a multiple of 1.971 to establish a common basis for comparing loads between the two watersheds. After area-adjustment, the Toms Creek watershed was equal in size to Back Creek (10,324.67 ha). The average annual sediment load (metric tons per year) from the area-adjusted Toms Creek defined the TMDL sediment load for Back Creek. The sediment loads for existing conditions were calculated using the period of January 1992 through March 2000 as representative of both wet and dry periods of precipitation. The target sediment TMDL load for existing conditions was **4,103 T/yr**. The existing load from Back Creek was **10,061 T/yr.** The benthic TMDL for Back Creek is composed of three components: waste load allocations (WLA) from point sources, load allocations (LA) from nonpoint sources, and a margin of safety (MOS), which was set to 10% for this study. The load allocation for existing conditions was **3,693 T/yr**.

Since urban development is expected to occur in Back Creek over the next 20 to 25 years, changes in landuse were estimated by modeling future loads as part of the allocation process. The broad based landuse change that was modeled resulted in an increase in developed land by 0.55% to 1.2%. The sediment load including future development was **11,047 T/yr.**

Load Allocation Scenarios

Fecal Coliform

The next step in the TMDL process was to reduce the various source loads to levels that would result in attainment of the water quality standards. Because Virginia's *E. coli* standard does not permit any exceedances of the standard, modeling was conducted for a target value of 0% exceedance of the 126 cfu/100 ml geometric mean standard and 0% exceedance of the sample maximum *E. coli* standard of 235 cfu/100 ml. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Modeling of these scenarios provided predictions of whether the reductions would achieve the target of 0% exceedance. The reductions in percentages in loading from existing conditions are given in Table ES.1. Scenario four, shows the reductions for the targets for Stage I implementation goals.

Table ES.1 Reduction percentages in loading from existing conditions.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations	
	Direct Wildlife	NPS Wildlife	Direct Livestock	NPS Pasture / Livestock	Res./ Urban	Straight Pipe/ Sewer Overflow	GM > 126 cfu/ 100ml	Single Sample Exceeds 235 cfu/ 100ml
1	0	0	0	0	0	0	100	82.6
2	0	0	0	0	0	100	100	82.6
3	0	0	90	50	50	100	76.7	36.7
4	0	0	100	60	60	100	63.3	31.9
5	0	0	100	99	99	100	0.0	2.74
6	75	75	100	99	99	100	0.0	1.48
7	99	99.5	100	99.5	99.5	100	0.0	0.44
8	38	93	100	99.8	95	100	0.0	0.0

General Standard (benthic) - Sediment

The reductions required to meet the TMDL considering future growth are shown in Table ES.2. To aid the development of TMDL allocation scenarios, nonpoint source areas were grouped into agriculture, urban and forestry categories. Sub-categories for agriculture (*i.e.*, hay, pastureland, cropland) and forestry (disturbed forest, undisturbed forest) were also included to provide a more specific allocation. The predominant sediment loads were from agriculture (cropland and pastureland) and the stream channel.

Table ES.2 Required reductions for Back Creek Watershed.

Load Summary	Back Creek	Reductions Required	
		(T/yr)	(% of existing load)
Future Projected Load	11,048	7,355	73.1
Existing Load	10,061	6,368	63.3
TMDL	4,103		
Target Modeling Load	3,693		

Two alternatives are presented in Table ES.3. Alternative 1 requires sediment reductions from all agricultural areas and channel (cropland 69%, pastureland 60%, and streambank erosion 65.8%). The reductions could be achieved through riparian buffers, streambank protection, livestock exclusion, improving pasture, reducing tillage operations, etc. Alternative 2 requires 60.1% reduction in streambank erosion, 69% reduction in erosion from pastureland, and a 90% reduction from cropland.

Table ES.3 TMDL sediment allocation scenarios for the Back Creek impairment.

Sediment Source Categories	Existing Condition (T/yr)	Allocations Alternative 1 (%)	Alternative 1 (T/yr)	Alternative 2 (%)	Alternative 2 (T/yr)
LDR-PER	3.507		3.507		3.507
HDR-PER	0.000		0.000		0.000
COM-PER	0.346		0.346		0.346
Transitional	32.080		32.080		32.080
Forest	73.023		73.023		73.023
Disturbed Forest	281.911		281.911		281.911
Pastureland	**2,543**	**60**	**1,017.4**	**69**	**788.5**
Cropland	**1,248**	**69**	**386.9**	**90**	**124.8**
LDR-IMP	10.155		10.155		10.155
HDR-IMP	0.000		0.000		0.000
COM-IMP	9.326		9.326		9.326
Water	0.000		0.000		0.000
NPS Load	4,201.961		1,741.638		1,323.641
Active Ag. BMPs	-603.350		-603.350		-603.350
Channel Erosion	7,448.921	**65.8**	**2,548**	**60.1**	**2972**
WLA	0.280		0.280		0.280
Total	**11,048**		**3,686**		**3,693**
Target Allocation Load (TMDL-MOS-WLA)			**3,693**		**3,693**

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria and General Standard (benthic) impairments on Back Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once EPA approves a TMDL, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent *Guidance Manual for Total Maximum Daily Load Implementation Plans*, published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice to control bacteria and minimize streambank erosion is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the direct cattle deposits and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock has been shown to reduce bank erosion. Improved pasture management including less intensive grazing, minimizing animal concentrations by frequent movement of winter feeding areas, improving pasture forages, etc, can significantly reduce soil loss from pasture areas. Reducing tillage operations, farming on the contour, strip cropping, maintaining a winter cover crop, etc. have shown to be effective measures to reduce erosion from cropland agriculture. Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

Watershed stakeholders will have the opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the Stage I scenario targeted controllable, anthropogenic bacteria and sediment sources.

Public Participation

During development of the TMDL for the Back Creek watershed, public involvement was encouraged through several meetings. A basic description of the TMDL process and the agencies involved was presented at the kickoff meeting on May 29, 2003. The Agricultural Subcommittee met on July 8, 2003. The first public meeting was held on October 14, 2003 to discuss the source assessment input, bacterial source tracking, and model calibration data. A "Field Day" was offered on November 18, 2003 to all stakeholders in the Back Creek, Crab Creek, and Peak Creek watershed areas. Participants were shown examples of aquatic life from a nearby reference stream, then looked at 2 sites on Back Creek to contrast the differences and discuss potential implementation strategies. The final model simulations and the TMDL load allocations were presented during the final public meeting on March 17, 2004. There was a 30 day-public comment period after the first and final public meetings and no written comments were received.

The meetings served to facilitate understanding of, and involvement in, the TMDL process. Posters that graphically illustrated the "state of the watershed" were on display at each meeting to provide an additional information component for the stakeholders. MapTech personnel were on hand to provide further clarification of the data as needed. Input from these meetings was utilized in the development of the TMDL and improved confidence in the allocation scenarios that were developed.

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PART I: BACKGROUND AND APPLICABLE STANDARDS

1. INTRODUCTION

1.1 Background

The need for TMDLs for the Back Creek watershed area was based on provisions of the Clean Water Act. The document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (United States Environmental Protection Agency, 1999), states:

> *According to Section 303(d) of the Clean Water Act and EPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs.*
>
> *…A TMDL is a tool for implementing State water quality standards, and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

The Back Creek watershed, located in Pulaski County, Virginia is part of the New River basin (Figure 1.1). Back Creek flows into the New River, which joins the Ohio River and flows into the Mississippi River. The Mississippi River then drains to the Gulf of Mexico.

According to the 1996 303(d) TMDL Priority List (VADEQ 1996), Back Creek was listed as impaired. The Virginia Department of Environmental Quality (VADEQ) has identified this segment as impaired with regard to both fecal coliform and the General Standard (benthic). Back Creek remained on the 1998 and 2002 303(d) lists for fecal impairment and was listed in 2002 for the General Standard (benthic) impairment.

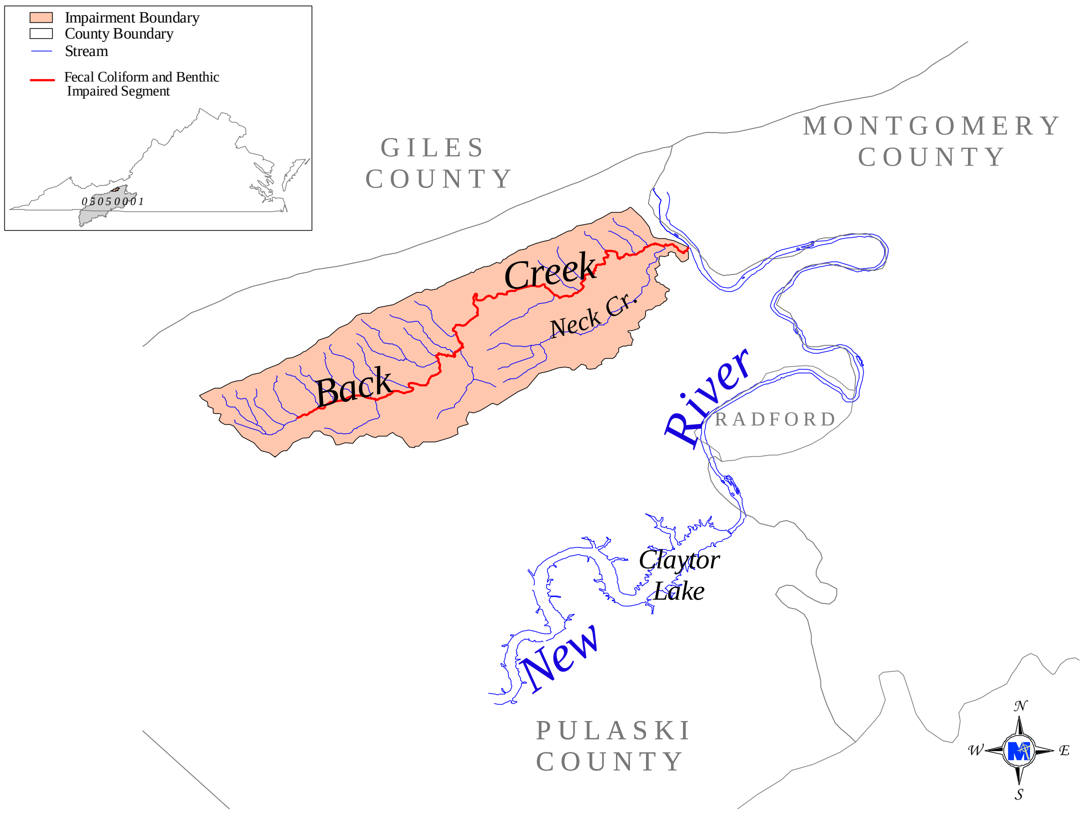


Figure 1.1 Location of the impaired stream in the Back Creek Watershed.

Back Creek (waterbody ID # VAW-N22R) was listed as impaired for fecal coliform during the 1996 assessment. Out of 16 samples collected at river mile 09.47 during the 1998 assessment period, 14 violated the fecal coliform standard. During the 2002 assessment period, 17 of 23 samples taken at river mile 09.47 violated the standard. A single benthic monitoring survey indicated severely impaired conditions in the Back Creek segment. The impairment of Back Creek begins 0.70 miles below the Rt. 636 crossing to the mouth of Back Creek on the New River.

The Back Creek watershed (USGS Hydrologic Unit Code #0505001) is part of the New River basin. The land area of the affected watersheds is approximately 25,500 acres, with pasture/hay and woodland as the primary landuses (Figure 1.2).

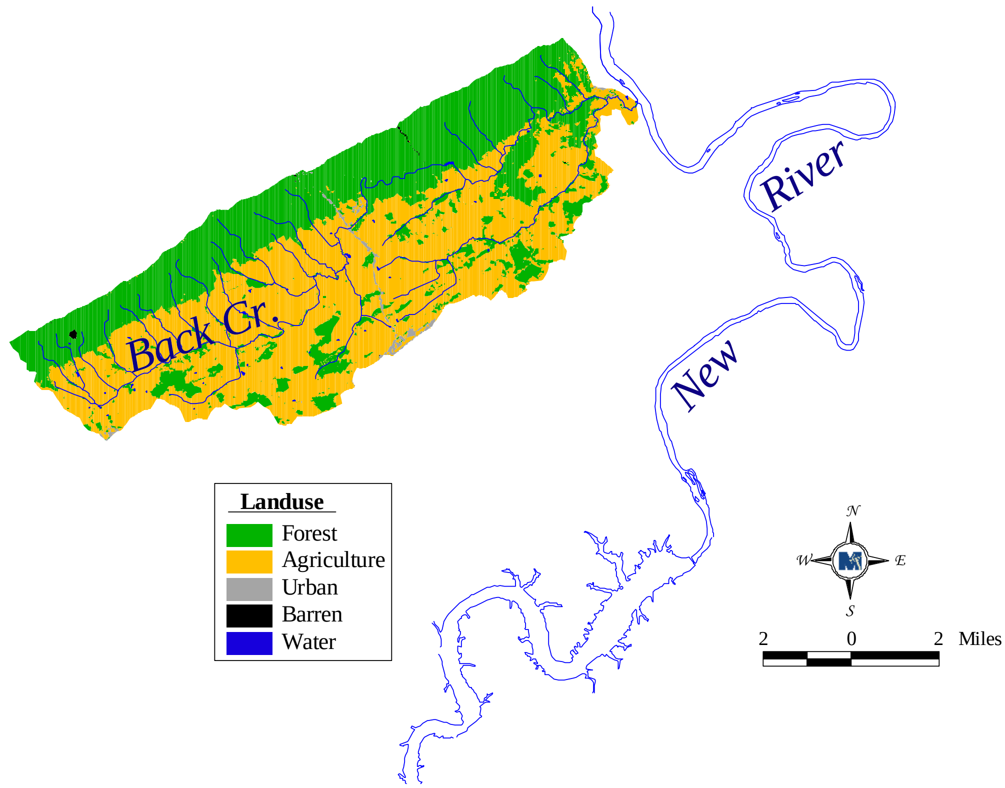


Figure 1.2 Landuses in the Back Creek Watershed.

The National Land Cover Data (NLCD) produced cooperatively between the U.S. Geological Survey (USGS) and U.S. Environmental Protection Agency (EPA) was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project lead by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 5 Thematic Mapper (TM) satellite images taken between 1990 and 1994, digital landuse coverage was developed identifying up to 21 possible landuse types. Classification, interpretation, and verification of the land cover dataset involved several data sources when available including: aerial photography; soils data; population and housing density data; state or regional land cover data sets; USGS landuse and land cover (LUDA) data; 3-arc second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and landuse proportions for each impaired segment are given in Table 1.1.

Table 1.1 Area affecting the impairment and contributing landuses.

Back Creek Landuse	Acreage
Water	13
Residential/Recreational	38
Commercial & Services	131
Barren	22
Woodland/Wetland	10,868
Pasture/Hay	12,344
Livestock Access	702
Cropland	1,337

The estimated human population within the drainage area is 1,888 (USCB, 1990, 2000). Among Virginia counties, Pulaski County ranks 19th for the number of dairy cows, 18th for the number of all cattle and calves, 18th for beef cattle, 6th for the number of sheep and lambs and 11th for production of corn silage (Virginia Agricultural Statistics, 2001). Pulaski County is also home to 471 species of wildlife, including 53 types of mammals (*e.g.*, beaver, raccoon, and white - tailed deer) and 418 types of birds (*e.g.*, wood duck, wild turkey, Canada goose) (VDGIF, 1999).

For the period from 1948 to 2000, the Back Creek watershed received average annual precipitation of approximately 37.11 inches, with 54% of the precipitation occurring during the May through October growing season (SERCC, 2002). Average annual snowfall is 11.8 inches with the highest snowfall occurring during February (SERCC, 2002). Average annual daily temperature is 52.8 ºF. The highest average daily temperature of 83.6 ºF occurs in July, while the lowest average daily temperature of 22.8 ºF occurs in January (SERCC, 2002).

1.2 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act."

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses),

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., <u>swimming and boating</u>; the propagation and growth of <u>a balanced, indigenous population of aquatic life</u>, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ♦
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*
>
> *G. The [State Water Control] board may remove a designated use which is not an existing use, or establish subcategories of a use, if the board can demonstrate that attaining the designated use is not feasible because:*
>
> 1. *Naturally occurring pollutant concentrations prevent the attainment of the use;*
> 2. *Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;*
>
> ♦
>
> 6. *Controls more stringent than those required by §§301(b) and 306 of the Clean Water Act would result in substantial and widespread economic and social impact.*

Because this study addresses both fecal coliform and benthic impairments, two water quality criteria are applicable. 9 VAC 25-260-170 applies to the fecal coliform impairment, whereas the General Standard section (9 VAC 25-260-20) applies to the benthic impairment.

1.3 Applicable Criteria for Fecal Coliform Impairment

Prior to 2002, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.*

If the waterbody exceeded either criterion more than 10% of the time, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set. If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. This was the criterion used for listing the impairments included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

EPA has since recommended that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. EPA is pursuing the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and *enterococci* standard is now in effect in Virginia as of January 15, 2003.

The new criteria, outlined in 9 VAC 25-260-170, read as follows:

A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:

1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.

2. E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:

	Geometric Mean[1]	*Single Sample Maximum*[2]
Freshwater[3]		
E. coli	*126*	*235*
Saltwater and Transition Zone[3]		
enterococci	*35*	*104*

[1] For two or more samples taken during any calendar month.

[2] No single sample maximum for enterococci and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.

[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

These criteria were used in developing the bacteria TMDLs included in this study.

1.4 Applicable Criterion for Benthic Impairment

The **General Standard,** as defined in Virginia state law 9 VAC 25-260-20, states:

> *A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.*

The General Standard is implemented by VADEQ through application of the Rapid Bioassessment Protocol II (RBP). Using the RBP, the health of the benthic macroinvertebrate community is typically assessed through measurement of 8 biometrics (Table 1.2) which measure different aspects of the community's overall health. Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level.

Each biometric measured at a target station is compared to the same biometric measured at a reference (non-impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.*, non-impaired, moderately impaired, or severely impaired).

Table 1.2 Components of the RBP Assessment.

Biometric	Benthic Health [1]
Taxa Richness	↑
Modified Family Biotic Index	↓
Scraper to Filtering Collector Ratio	↑
EPT / Chironomid Ratio	↑
% Contribution of Dominant Family	↓
EPT Index	↑
Community Loss Index	↓
Shredder to Total Ratio	↑

[1] An upward arrow indicates a positive response in benthic health when the associated biometric increases.

PART II: FECAL BACTERIA TMDLS

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Selection of a TMDL Endpoint and Critical Condition

Back Creek was initially placed on the Virginia 1996 303(d) TMDL Priority List based on monitoring performed. Back Creek remained on the 2002 303(d) Report on Impaired Waters. Elevated levels of fecal coliform bacteria recorded at VADEQ ambient water quality monitoring stations showed that this stream segment does not support the primary contact recreation use.

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Back Creek TMDL, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations (Section 1.2 of this document). In order to remove a water body from a state's list of impaired waters; the Clean Water Act requires compliance with that state's water quality standard. Since modeling provided simulated output of *E. coli* concentrations at 1-hour intervals (Section 4.2 of this document), assessment of TMDLs was made using both the geometric mean standard of 126 cfu/100 ml and the instantaneous standard of 235 cfu/100 ml. Therefore, the in-stream *E. coli* targets for these TMDLs were a monthly geometric mean not exceeding 126 cfu/100 ml and a single sample not exceeding 235 cfu/100 ml.

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Back Creek is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and help in identifying the actions that may have to be undertaken to meet water quality standards. Fecal coliform sources within the Back Creek watershed are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context, also include nonpoint sources that are not precipitation driven (*e.g.*, direct fecal deposition to stream).

A graphical analysis of measured fecal coliform concentrations versus the level of flow at the time of measurement showed that there was no obvious critical flow level (Figure 2.1). That is, the analysis showed no dominance of either nonpoint sources or point sources. High concentrations were recorded in all flow regimes. Based on this analysis, a time period for calibration and modeling allocation scenarios was chosen based on the overall distribution of wet and dry seasons (Section 4.5). The resulting period was October 1980 through September 1985.

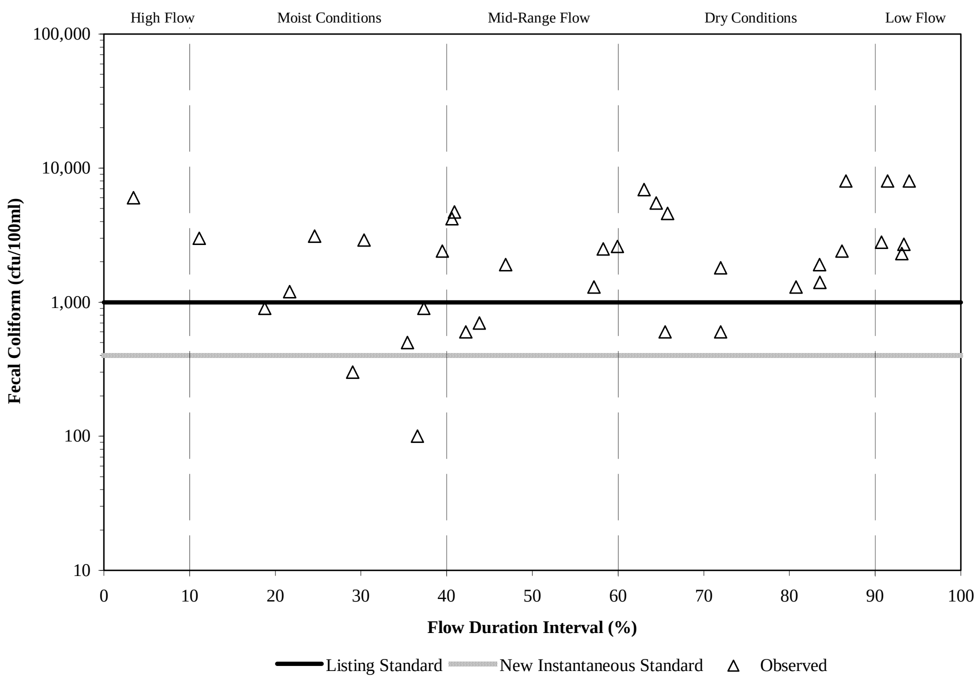


Figure 2.1 Relationship between fecal coliform concentrations (VADEQ Station 9BCK009.47) and discharge in Back Creek.

2.2 Discussion of In-stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal coliform monitoring data throughout the Back Creek watershed. An examination of data from water quality stations used in the 303(d) assessment and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

2.2.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- bacteria enumerations from 3 VADEQ in-stream monitoring stations used for TMDL assessment; and
- bacteria enumerations and bacterial source tracking from 2 VADEQ in-stream monitoring stations analyzed during TMDL development.

2.2.1.1 Water Quality Monitoring for TMDL Assessment

Data from in-stream fecal coliform samples, collected by VADEQ, were analyzed from August 1992 through February 2004 (Figure 2.2) and are included in the analysis. Samples were taken for the express purpose of determining compliance with the state instantaneous standard limiting concentrations to less than 1,000 cfu/100 ml. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 ml or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 ml, depending on the laboratory procedures employed for the sample) were not further analyzed to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 100 cfu/100 ml most likely represent concentrations below 100 cfu/100 ml, and reported concentrations of 8,000 or 16,000 cfu/100 ml most likely represent concentrations in excess of these values. Table 2.1 summarizes the fecal coliform samples collected at the in-stream monitoring stations used for TMDL assessment.

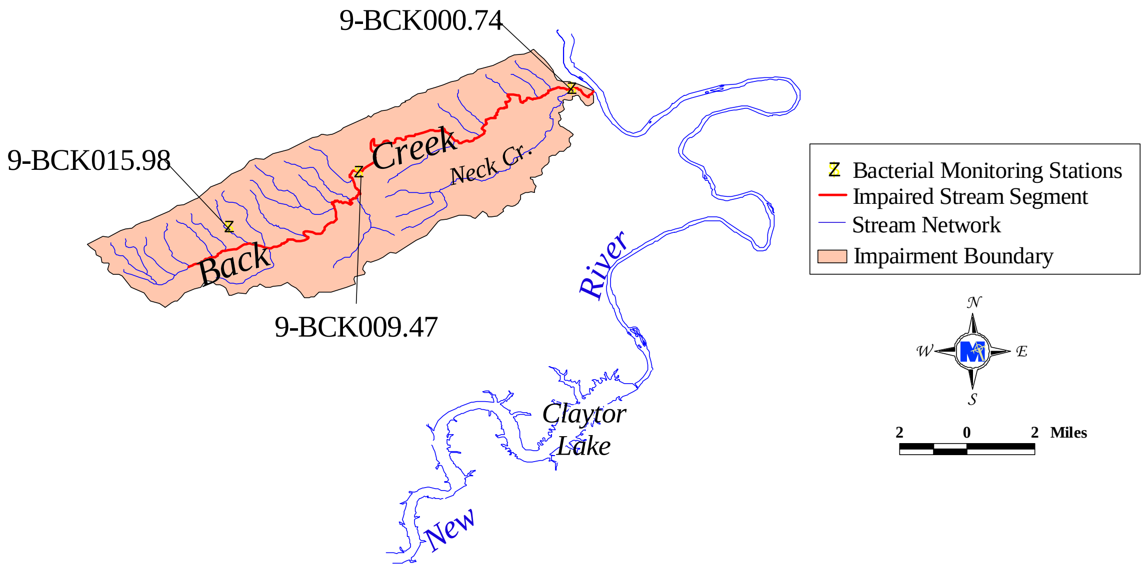


Figure 2.2 Location of VADEQ water quality monitoring stations used for TMDL assessment in the Back Creek watershed.

Table 2.1 Summary of fecal coliform monitoring conducted by VADEQ for period August 1992 through February 2004.

Impairment	VADEQ Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] %	Violations[2] %
Back Creek	9-BCK000.74	21	18	11,000	1,410	690	38	67
Back Creek	9-BCK009.47	35	100	8,000	2,817	2,400	74	94
Back Creek	9-BCK015.98	10	68	5,400	1,783	960	50	70

[1] Violations are based on the pre-2003 fecal coliform instantaneous standard (*i.e.*, 1,000 cfu/100ml)
[2] Violations are based on the interim fecal coliform instantaneous standard (*i.e.*, 400 cfu/100ml)

2.2.1.2 Water Quality Monitoring Conducted During TMDL Development

Ambient water quality monitoring was performed from August 1992 through June 2001. Specifically, water quality samples were taken at two sites in the Back Creek watershed (Figure 2.3). All samples were analyzed for fecal coliform and *E. coli* concentrations, and for bacteria source (*i.e.*, human, livestock, pets, wildlife) by the Environmental Diagnostics Laboratory (EDL) at MapTech. Table 2.2 and Table 2.3 summarize the fecal coliform and *E. coli* concentration data, respectively, at the ambient stations. Bacterial source tracking (BST) is discussed in greater detail in Section 2.2.2.2.

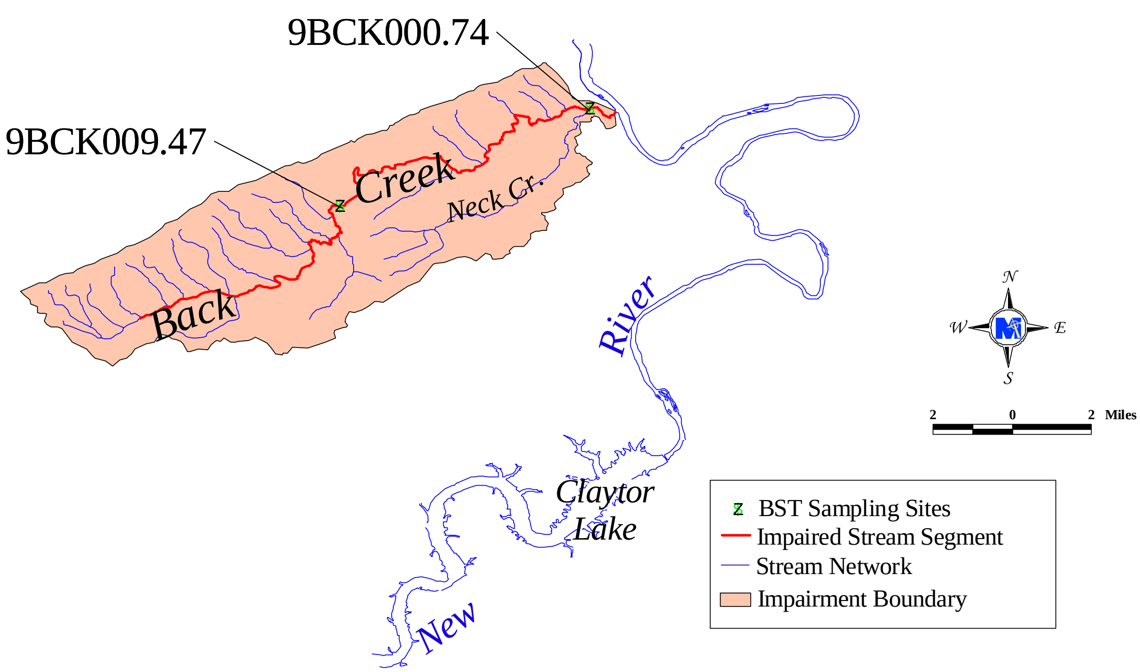


Figure 2.3 Location of BST water quality monitoring stations in the Back Creek watershed.

Table 2.2 Summary of water quality sampling conducted by VADEQ during TMDL development. Fecal coliform concentrations (cfu/100 ml).

Impairment	Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] (%)	Violations[2] (%)
Back Creek	9BCK000.74	12	300	11,000	2,058	815	42	75
Back Creek	9BCK009.47	12	520	24,000	5,368	3,100	83	100

[1]Violations based on listing fecal coliform instantaneous standard (*i.e.*, 1,000 cfu/100ml)
[2]Violations based on new fecal coliform instantaneous standard (*i.e.*, 400 cfu/100ml)

Table 2.3 Summary of water quality sampling conducted by VADEQ during TMDL development. *E. coli* concentrations (cfu/100 ml).

Impairment	Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] (%)
Back Creek	9BCK000.74	12	1	9,000	1,238	465	83
Back Creek	9BCK009.47	12	310	18,000	2,707	1,150	100

[1]Violations based on *E. coli* instantaneous standard (*i.e.*, 235 cfu/100ml)

2.2.1.3 Summary of In-stream Water Quality Monitoring Data

A wide range of fecal coliform concentrations have been recorded in the watershed. Concentrations reported during TMDL development were within the range of historical values reported by VADEQ during TMDL assessment. Exceedances of the instantaneous standard were reported in all flow regimes, leaving no apparent relationship between flow and water quality.

2.2.2 Analysis of Water Quality Monitoring Data

The data collected were analyzed for frequency of violations, patterns in fecal source identification, and seasonal impacts. Results of the analyses are presented in the following sections.

2.2.2.1 Summary of Frequency of Violations at the Monitoring Stations

All water quality data were collected at a time-step of at least one month. The state standard of 1,000 cfu/100 ml and 400 cfu/100 ml was used to test for fecal coliform violations. For samples with *E. coli* concentrations, violations of the state standard of 235 cfu/100 ml were calculated. Violation rates are listed in Table 2.1 through Table 2.3. A distribution of fecal coliform concentrations at each sampling station in the watershed can be found in Appendix A. Violations were persistent across the sampled period.

2.2.2.2 Bacterial Source Tracking

MapTech, Inc. was contracted to do analyses of fecal coliform and *E. coli* concentrations as well as bacterial source tracking. Bacterial source tracking is intended to aid in identifying sources (*i.e.*, human, pets, livestock, or wildlife) of fecal contamination in water bodies. Data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chances for success in implementing solutions.

Several procedures are currently under study for use in BST. Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology implemented by MapTech's EDL.

This method was selected because it has been demonstrated to be a reliable procedure for confirming the presence or absence of human, pet, livestock and wildlife sources in watersheds in Virginia. The results of sampling were reported as the percentage of isolates acquired from the sample. These isolates were identified as originating from either human, pet, livestock, or wildlife sources.

In spite of the high quality of the data collected, care should be taken in using these data. These data represent, at most, 12 instantaneous observations at each station and may not be representative of long-term conditions. The hydrologic conditions during this period were extreme, beginning with drought and ending with some of the wettest seasons on record. Additionally, the dynamics of the bacterial community are not well understood, so care should be taken in extrapolating from the in-stream condition to activities in the watershed. As with any other monitoring program, the data should not be viewed in a vacuum. Local knowledge of the sources involved, historical water quality records, and the hydrologic conditions during sampling should all be considered in any interpretation of this data.

BST results of water samples collected at two ambient stations in the Back Creek drainage area are reported in Table 2.4. The BST results indicate the presence of all sources (*i.e.*, human, livestock, wildlife, and pets) contributing to the fecal bacteria violations. The fecal coliform and *E. coli* enumerations are given to indicate the bacteria concentration at the time of sampling. The proportions reported are formatted to indicate statistical significance (*i.e.*, **BOLD** numbers indicate a statistically significant result). The statistical significance was determined through 2 tests. The first was based on the sample size. A z-test was used to determine if the proportion was significantly different from zero (alpha = 0.10). Second, the rate of false positives was calculated for each source category in each library, and a proportion was not considered significantly different from zero unless it was greater than the false-positive rate plus three standard deviations.

Table 2.4 Summary of bacterial source tracking results from water samples collected in the Back Creek impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as[1]: Human	Pets	Livestock	Wildlife
9-BCK000.74	11/25/02	370	<1	--	--	**--**	--
	12/17/02	2,000	300	0	**13**	**62**	**25**
	1/29/03	830	680	**29**	**54**	0	**17**
	2/25/03	300	140	4	**29**	**42**	**25**
	3/31/03	11,000	9,000	4	**33**	**50**	**13**
	4/29/03	430	330	**22**	**22**	**43**	**13**
	5/2803	2,000	540	**42**	**29**	**25**	4
	6/26/03	800	610	0	**17**	**38**	**45**
	7/22/03	690	390	0	4	**71**	**25**
	8/27/03	3,900	620	0	0	**96**	4
	9/22/03	2,000	1,900	**50**	0	**21**	**29**
	10/22/03	380	340	0	**12**	**76**	**12**
9-BCK009.47	11/25/02	520	500	**88**	8	4	0
	12/17/02	9,000	2,200	0	0	**33**	**59**
	1/29/03	2,000	950	**29**	**33**	**17**	**21**
	2/25/03	4,000	1,200	8	**29**	**59**	0
	3/31/03	24,000	18,000	**29**	**50**	**13**	8
	4/29/03	2,200	900	**21**	**62**	4	**13**
	5/28/03	3,000	2,100	**38**	0	**41**	**21**
	6/26/03	3,000	920	**17**	**21**	**41**	**21**
	7/22/03	3,200	1,100	**58**	0	**25**	**17**
	8/27/03	6,900	1,700	4	**38**	**25**	**33**
	9/22/03	6,000	2,600	**17**	**17**	**33**	**33**
	10/22/03	600	310	4	**17**	8	**71**

[1]**BOLD** type indicates a statistically significant value.

2.2.2.3 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on precipitation, and fecal coliform concentrations. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

A seasonal analysis of precipitation, and fecal coliform concentration data was conducted using the Mood Median Test. This test was used to compare median values of precipitation and fecal coliform concentrations in each month. No significant differences between months within years were reported.

2.2.2.4 Precipitation

Total monthly precipitation measured at NWS Station #446955 in Pulaski County was analyzed, and no overall, long-term trend or seasonality was observed.

2.2.2.5 Fecal Coliform Concentrations

Water quality monitoring data collected by VADEQ were described in section 2.2.1.1. The trend analysis was conducted on data, if sufficient, collected at stations used in TMDL assessment (Table 2.5). There were no stations with a significant seasonality effect.

Table 2.5 Summary of trend analysis on fecal coliform (cfu/100 ml).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
BCK000.74	531.25	410	1,300	100	441.15	8	--
BCK009.47	2,982.56	2,400	8,000	100	2,337.30	43	--
BCK015.98	2,362.86	2,400	5,400	110	1,921.34	7	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data

3. FECAL COLIFORM SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential significant sources of fecal coliform in the Back Creek watershed. The source assessment was used as the basis of water quality model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local, state, and federal management agencies. This section documents the available information and interpretation for the TMDL analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in Section 4.

3.1 Assessment of Point Sources

Point sources permitted to discharge in the Back Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES) are listed in Table 3.1 and shown in Figure 3.1. There are currently no Municipal Separate Storm Sewer Systems (MS4) permitted discharges in the watershed. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. Currently, these permitted dischargers are expected not to exceed the 126 cfu/100ml *E. coli* standard. The two discharges permitted for fecal bacteria control are small (<1,000 gallons/day) private residences. These systems are assumed to meet the criteria described above.

Table 3.1 Permitted Point Sources in the Back Creek Watershed.

Facility	VPDES #	Design Discharge (MGD)	Permitted For Fecal Control	Data Availability
Residence	VAG402033	0.0005	Yes	No Data
Residence	VAG402086	.001	Yes	No Data
Back Creek Dairy	VPG120009		-----------NO DISCHARGE-----------	
Goochs Recycling	VAR050140	Stormwater	No	No Data

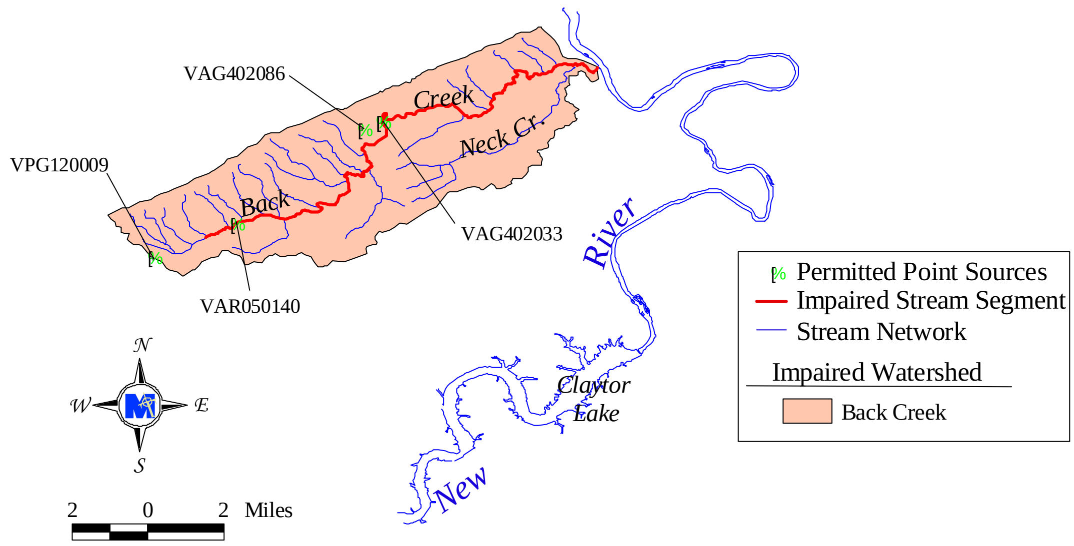


Figure 3.1 Location of VPDES permitted point sources in the Back Creek watershed.

3.2 Assessment of Nonpoint Sources

In the Back Creek watershed, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, land application of waste (livestock and biosolids), livestock, wildlife, and pets. Sources were identified and enumerated. Where appropriate, spatial distribution of sources throughout the watershed was also determined.

3.2.1 Private Residential Sewage Treatment

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and should be periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried absorption trenches consisting of perforated pipes enclosed in beds of gravel. This combination of pipes and trenches comprise the drainage field. Once in the soil, the effluent may potentially flow downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by filtration by the soil matrix and die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters (ground and surface water). Properly designed, installed, and functioning septic systems that are more than 50 feet from a stream are considered to contribute virtually no fecal coliform to surface waters. Reneau (2000) reported that a very small portion of fecal coliform can survive in the soil system for over 50 days. This number might be higher or lower depending on soil moisture, temperature, and physical characteristics such as soil structure and texture.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A permit from the Virginia Department of Health (VDH) is required for installing or repairing a septic system. A survey of septic pump-out contractors performed by MapTech showed that failures were more likely to occur in the winter to spring months than in the summer to fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed on the surface of the yard.

Table 3.2 indicates the human population contributing to the impairment, projected to current numbers based on 1990 and 2000 Census data. Due to the aggregation of census data from geographical units developed for the census (*i.e.*, census blocks and groups) to subwatersheds, some slight errors occurred (*e.g.*, small numbers of homes with sewer service indicated in subwatersheds where no service is available). These slight errors were controlled based on validation with public review and cross-referencing with other data sources (*e.g.*, public service authorities). The number of households that reported in the 1990 Census a system other than sewer or septic are an indicator of the potential number of households depositing sewage directly to the stream.

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 ml. An average fecal coliform density for human waste of 13,000,000 cfu/g was reported by Geldreich (1978) and a total wastewater load of 75 gal/day/person for households utilizing septic systems, with typical septic tank effluent having fecal coliform concentrations of 10,000 cfu/100 ml (Metcalf and Eddy, 1991).

Table 3.2 Human population, housing units, houses on sanitary sewer, houses on septic systems, and houses on other treatment systems for 2003 in the Back Creek watershed.[1]

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other [2]
Back Creek	1,888	844	32	801	11

[1]U.S. Census Bureau.
[2] Houses with treatment systems other than sanitary sewer and septic systems.

3.2.2 Livestock

The predominant types of livestock in the Back Creek watershed are beef and dairy cattle, sheep, and horses, although all types of livestock identified were considered in modeling the watershed. Animal populations were based on communication with Natural Resources Conservation Service (NRCS), Skyline Soil and Water Conservation District (SSWCD), watershed visits, verbal communication with farmers, and review of all publicly available information on animal type and approximate numbers known to exist within Pulaski County and the TMDL project areas. Table 3.3 gives estimates of livestock populations in the Back Creek watershed. Fecal coliform density values for livestock sources were based on sampling performed by MapTech. Reported manure production rates for livestock were taken from ASAE, 1998. A summary of fecal coliform density values and manure production rates is presented in Table 3.4.

Table 3.3 Estimated livestock populations in the Back Creek watershed.

Watershed	Beef Cattle	Dairy Cattle	Horse	Sheep
Back Creek	4,478	607	245	1,000

Table 3.4 Average fecal coliform densities and waste loads associated with livestock. [1]

Type	Waste Load (lb/d/an)	FC Density (cfu/g)
Dairy (1,400 lb)	120.4	258,000
Beef (800 lb)	46.4	101,000
Horse (1,000 lb)	51.0	94,000
Sheep (60 lb)	2.4	43,000
Dairy Separator	N/A	32,000[2]
Dairy Storage Pit	N/A	1,200[2]

[1]American Society of Agricultural Engineers.
[2]units are cfu/100ml

Fecal coliform bacteria produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.*, pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Second, grazing livestock deposit manure directly on the land, where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams.

All grazing livestock were expected to deposit some portion of waste on pasture land areas. The percentage of time spent on pasture for dairy and beef cattle was reported by SWCD, NRCS, VADCR, and VCE personnel (Table 3.6 through Table 3.8). Horses, sheep, and beef cattle were assumed to be in pasture 100% of the time. The average amount of time spent by dairy and beef cattle in stream access areas (*i.e.*, within 100 feet of the stream) for each month is given in Table 3.6 through Table 3.8.

Table 3.5 Average percentage of collected dairy waste applied throughout year.[1]

Month	Applied % of Total	Landuse
January	1.50	Cropland
February	1.75	Cropland
March	17.00	Cropland
April	17.00	Cropland
May	17.00	Cropland
June	1.75	Pasture
July	1.75	Pasture
August	1.75	Pasture
September	5.00	Cropland
October	17.00	Cropland
November	17.00	Cropland
December	1.50	Cropland

[1]Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD).

Table 3.6 Estimated average time dairy milking cows spend in different areas per day. [1]

Month	Pasture (hr)	Stream (hr)	Loafing Lot (hr)
January	2.5	0.17	21.4
February	2.5	0.17	21.4
March	3.5	0.26	20.2
April	5.4	0.34	18.2
May	6.3	0.34	17.3
June	6.9	0.43	16.7
July	7.6	0.43	16.0
August	7.6	0.43	16.0
September	7.7	0.34	16.0
October	7.3	0.26	16.4
November	6.4	0.26	17.3
December	4.7	0.17	19.1

[1] Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD),Virginia Department of Conservation and Recreation, and Virginia Cooperative Extension.

Table 3.7 Estimated average time dry cows and replacement heifers spend in different areas per day. [1]

Month	Pasture (hr)	Stream (hr)	Loafing Lot (hr)
January	23.3	0.72	0.0
February	23.3	0.72	0.0
March	22.6	1.44	0.0
April	21.8	2.16	0.0
May	21.8	2.16	0.0
June	21.1	2.88	0.0
July	21.1	2.88	0.0
August	21.1	2.88	0.0
September	21.8	2.16	0.0
October	22.6	1.44	0.0
November	22.6	1.44	0.0
December	23.3	0.72	0.0

[1] Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD),Virginia Department of Conservation and Recreation, and Virginia Cooperative Extension.

Table 3.8 Estimated average time beef cows spend in different areas per day. [1]

Month	Pasture (hr)	Stream (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

[1] Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD),Virginia Department of Conservation and Recreation, and Virginia Cooperative Extension.

3.2.3 Biosolids

The rate of biosolids application in the Back Creek watershed is relatively small. The Peppers Ferry Regional Wastewater Treatment Authority (RWTA) is the source of biosolids. Table 3.9 shows the amount of biosolids produced and distributed in the affected watershed by source and year. Table 3.10 shows acreages permitted for biosolids application and the actual application information. The sensitivity analysis for this study will include modeling application of the maximum permitted level on permitted sites in the watershed.

Table 3.9 Sources of biosolids spread (dry tons) in the Back Creek watershed.

Source	1995	1996	1997	1999	2000	2003
Peppers Ferry RWTA	3.40	3.00	2.50	1.00	1.40	2.75

Table 3.10 Acreages permitted for biosolids applications and actual applications by subwatershed in the Back Creek watershed.

Impairment	Subwatersheds	Acres Permitted	Acres Applied (1994-2003)	Dry Tons Applied (1994-2003)	Fecal Coliform Applied
Back Creek	BK01	0.00	0.00	0.00	0.00E+00
	BK02	0.00	0.00	0.00	0.00E+00
	BK03	0.00	0.00	0.00	0.00E+00
	BK04	145.00	145.00	14.05	2.50E+11
	BK05	0.00	0.00	0.00	0.00E+00
TOTAL		145.00	145.00	14.05	2.50E+11

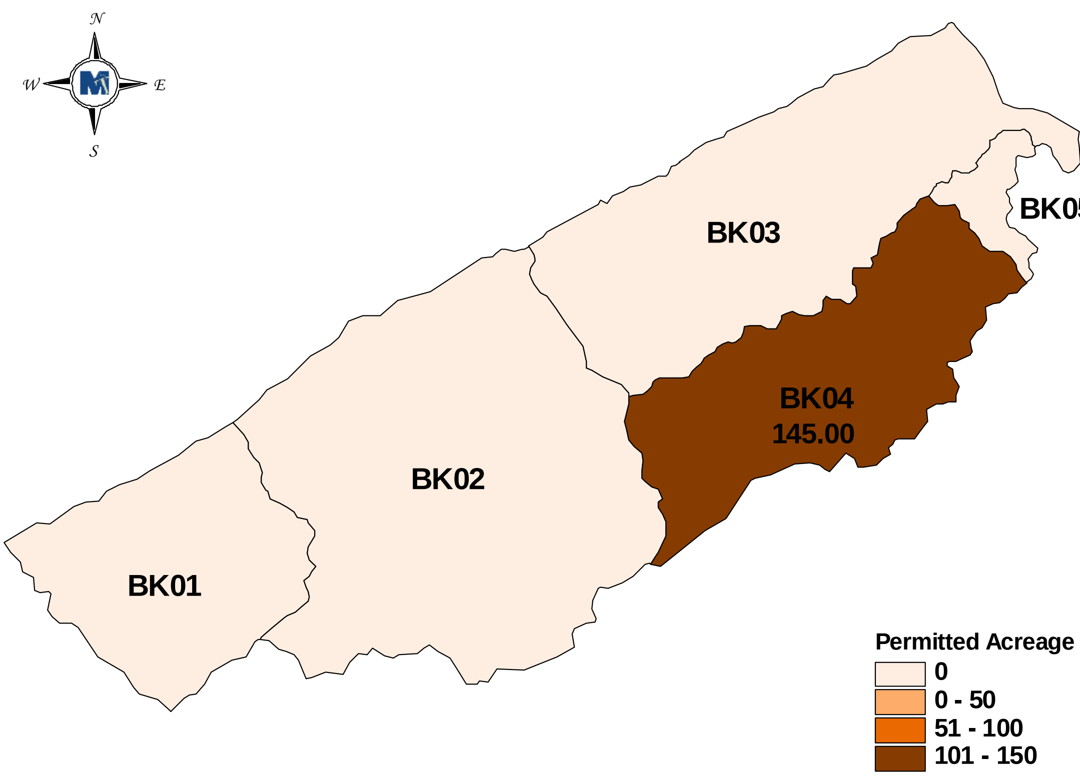


Figure 3.2 Location of acres permitted for biosolids application in the Back Creek watershed.

3.2.4 Wildlife

The predominant wildlife species in the watershed were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), citizens from the watershed, source sampling, and site visits. Population densities were provided by VDGIF and are listed in Table 3.11 (Bidrowski, 2003; Costanzo, 2003; Farrar, 2003; Knox, 2003; Norman and Lafon, 2002; and Rose and Cranford, 1987). The estimated numbers of animals in the Back Creek watershed are reported in Table 3.12. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996; and Yagow, 1999). Table 3.13 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on wildlife waste sampling performed by MapTech. The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999). Percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling for other projects. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.,* within 100 feet of stream) are reported in Table 3.14.

Table 3.11 Wildlife population density.

Wildlife	Pulaski County Density	Density Unit
Raccoon	0.0703	an/ac of habitat
Muskrat	2.75	an/ac of habitat
Beaver	4.8	an/mi of stream
Deer	0.041	an/ac of habitat
Turkey	0.015	an/ac of forest
Goose	0.003	an/ac
Duck	0.0146	an/ac

Table 3.12 Estimated wildlife populations in the Back Creek watershed.

Watershed	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
Back Creek	1,029	358	7	26	3,720	1,730	132

Table 3.13 Wildlife fecal production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of continuous streams Infrequent = region between 601 and 7,920 ft from continuous streams
Muskrat	100	Primary = region within 66 ft from continuous streams Less frequent = region between 67 and 308 ft
Beaver[1]	200	Continuous stream below 500 ft elevation (defined as distance in feet)
Deer	772	Primary = forested, harvested forest land, orchards, grazed woodland, open urban, cropland, pasture Infrequent = low density residential, medium density residential Seldom/None = rest of landuse codes
Turkey[2]	320	Primary = forested, harvested forest land, grazed woodland Infrequent = open urban, orchards, cropland, pasture Seldom/None = Rest of landuse codes
Goose[3]	225	Primary = region within 0-66 ft from ponds and continuous streams Infrequent = region between 67 and 308 ft from ponds and continuous streams
Duck	150	Primary = region within 0-66 ft from ponds and continuous streams Infrequent = region between 67 and 308 ft from ponds and continuous streams

[1]Beaver waste load was calculated as twice that of muskrat, based on field observations.
[2]Waste load for domestic turkey (ASAE, 1998).
[3]Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003).

Table 3.14 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Turkey	1,332	5
Goose	250,000	50
Duck	3,500	75

3.2.5 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the watershed and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was measured. Fecal coliform density for dogs and cats was measured from samples collected throughout Virginia by MapTech. A summary of the data collected is given in Table 3.15. Table 3.16 lists the domestic animal populations for the watershed.

Table 3.15 Domestic animal population density, waste load, and fecal coliform density.

Type	Population Density (an/house)	Waste load (g/an-day)	FC Density (cfu/g)
Dog	0.534	450	480,000
Cat	0.598	19.4	9

Table 3.16 Estimated domestic animal populations in the Back Creek watershed.

Watershed	Dog	Cat
Back Creek	450	504

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of a TMDL for the Back Creek watershed, the relationship was defined through computer modeling based on data collected throughout the study area. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration/validation, and model application are discussed.

4.1 Modeling Framework Selection

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and to perform TMDL allocations. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed.

The HSPF model simulates a watershed by dividing it up into a network of stream segments (referred to in the model as RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various landuses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

4.2 Model Setup

To adequately represent the spatial variation in the watershed, the Back Creek drainage areas were divided into five subwatersheds (Figure 4.1). The rationale for choosing these subwatersheds was based on the availability of water quality data and the limitations of the HSPF model. Water quality data (*i.e.*, fecal coliform concentrations) are available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with these monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets (Figure 4.1 and Table 4.1). In an effort to standardize modeling efforts across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

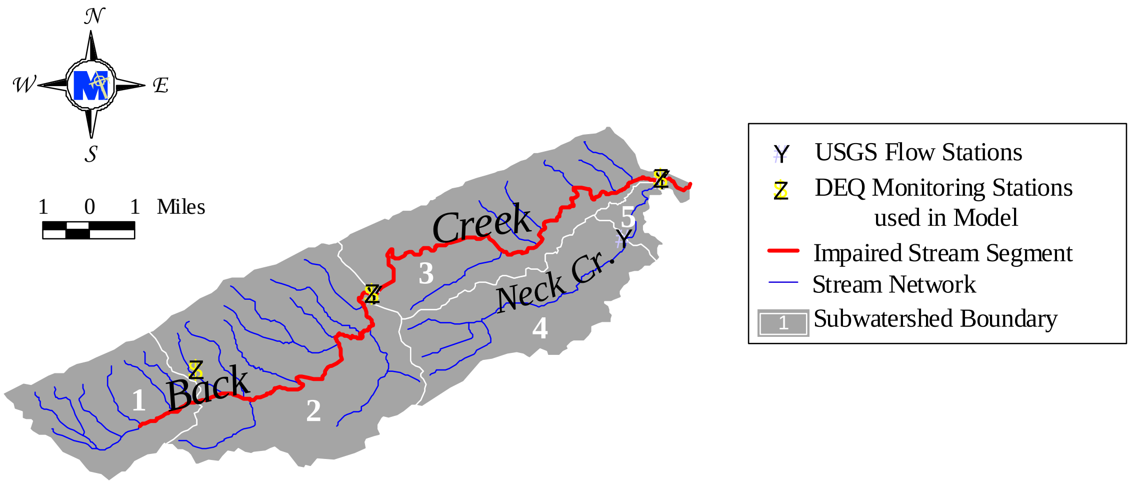


Figure 4.1 Subwatersheds delineated for modeling and location of VADEQ water quality monitoring stations and USGS Gaging Station in the Back Creek watershed.

Table 4.1 VADEQ monitoring stations and corresponding reaches in the Back Creek watershed.

Station Number	Reach Number
9-BCK015.98	19
9-BCK009.47	20
9-BCK000.74	23

Using aerial photographs, MRLC identified up to 21 possible landuse types in the watershed. The landuse types were consolidated into eight categories based on similarities in hydrologic and waste application/production features (Table 4.2). Within each subwatershed, up to the eight landuse categories were represented. Each landuse had parameters associated with it that described the hydrology of the area (*e.g.*, average slope length) and the behavior of pollutants (*e.g.*, fecal coliform accumulation rate). Table 4.3 shows the consolidated landuse types and the area existing in the impairment. These landuse types are represented in HSPF as PERLNDs and IMPLNDs. Impervious areas in the watershed are represented in three IMPLND types, while there are seven PERLND types, each with parameters describing a particular landuse (Table 4.2). Some IMPLND and PERLND parameters (*e.g.*, slope length) vary with the particular subwatershed in which they are located. Others vary with season (*e.g.*, upper zone storage) to account for plant growth, die-off, and removal.

Table 4.2 Consolidation of MRLC landuse categories for the Back Creek watershed.

TMDL Landuse Categories	Pervious / Impervious (Percentage)	MRLC Landuse Classifications (Class No.)
Water	Impervious (100%)	Open Water (11)
Residential/Recreational	Pervious (70%) Impervious (30%)	Low Intensity Residential (21) High Intensity Residential (22) Urban/Recreational Grasses (85)
Commercial and Services	Pervious (70%) Impervious (30%)	Commercial/Industrial/Transportation (23)
Barren	Pervious (100%)	Transitional (33) Quarries/Strip Mines/Gravel Pits (32)
Woodland/Wetland	Pervious (100%)	Evergreen Forest (42) Deciduous Forest (41) Mixed Forest (43) Emergent Herbaceous Wetlands (92) Woody Wetlands (91)
Pasture	Pervious (100%)	Pasture/Hay (81)
Cropland	Pervious (100%)	Row Crops (82)
Livestock Access	Pervious (100%)	Pasture/Hay (81)

Table 4.3 Spatial distribution of landuse types in the Back Creek drainage area.

Landuse	Back Creek Acreage
Water	13
Residential/Recreational	38
Commercial & Services	131
Barren	22
Woodland/Wetland	10,868
Pasture/Hay	12,344
Livestock Access	702
Cropland	1,337

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (mechanically applied and deposited directly), die-off was addressed implicitly through monitoring and modeling. Samples of accumulated waste prior to land application (*i.e.*, dairy waste from loafing areas) were collected and analyzed by MapTech. Therefore, die-off is implicitly accounted for through the sample analysis. Die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with landuse type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.,* animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by nocturnal animals were modeled as being deposited from 6:00 PM to 6:00 AM, and direct depositions by diurnal animals were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.,* population). Depending on the timeframe of the simulation being run, different numbers should be used. Data representing 1995 were used for the water quality calibration and validation period (1993-2003). Data representing 2003 were used for the allocation runs in order to represent current conditions. Additionally, data projected to 2008 were analyzed to assess the impact of changing populations.

4.3.1 Point Sources

For permitted point dischargers, design flow capacities were used for allocation runs. This flow rate was combined with a fecal coliform concentration of 200 cfu/100 ml for discharges permitted for fecal control, to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels. For calibration and current condition runs, a lower value of fecal coliform concentration was used, based upon a regression analysis relating Total Residual Chlorine (TRC) levels and fecal coliform concentrations (VADEQ/VADCR, 2000). Nonpoint sources of pollution that were not driven by runoff (*e.g.,* direct deposition of fecal matter to the the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

4.3.2 Private Residential Sewage Treatment

The number of septic systems in the subwatersheds modeled for the Back Creek watershed was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watershed to enumerate the septic systems. Households were then distributed among residential landuse types. Each landuse area was assigned a number of septic systems based on census data. A total of 801 septic systems were estimated in the Back Creek watershed in 1995. During allocation runs, the number of households was projected to 2003, based on current Pulaski County growth rates (USCB, 2000) resulting in 801 septic systems (Table 4.4). The number of septic systems was projected to increase to 1,882 by 2008.

Table 4.4 Estimated failing septic systems (2003).

Impaired Segment	Total Septic Systems	Failing Septic Systems	Straight Pipes
Back Creek	801	171	2

4.3.2.1 Failing Septic Systems

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. In accordance with estimates from Raymond B. Reneau, Jr. of the Crop and Soil Environmental Sciences Department at Virginia Tech, a 40% failure rate for systems designed and installed prior to 1964, a 20% failure rate for systems designed and installed between 1964 and 1984, and a 5% failure rate on all systems designed and installed after 1984 was used in development of a TMDL for the Back Creek watershed. Total septic systems in each category were calculated using U.S. Census Bureau block demographics. The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors (VADEQ/VADCR, 2000) to account for more frequent failures during wet months.

4.3.2.2 Uncontrolled Discharges

Uncontrolled discharges were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category “other means” were assumed to be disposing sewage via uncontrolled discharges if located within 200 feet of a stream. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. A 200-foot buffer was created from the stream segments. The corresponding buffer and subwatershed areas were intersected resulting in uncontrolled discharges within 200 feet of the stream per subwatershed. Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the waste load for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model.

4.3.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The number of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers determined for 2003 were used for the allocation runs, while these numbers were projected back to 1995 for the calibration and validation runs. The numbers are based on data provided by SWCD, and NRCS, as well as taking into account growth rates in Pulaski County (as determined from data reported by the Virginia Agricultural Statistics Service -- VASS, 1995 and VASS, 2003). Similarly, when growth was analyzed, livestock numbers were projected to 2008. For land-applied waste, the fecal coliform density measured from stored waste was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.4). The use of fecal coliform densities measured in stored manure accounts for any die-off that occurs in storage. The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

4.3.3.1 Land Application of Collected Manure

Significant collection of livestock manure occurs on dairy farms. For dairy farms in the drainage area, the average daily waste production per month was calculated using the number of animal units, weight of animal, and waste production rate as reported in Section 3.2.2. The amount of waste collected was first based on proportion of milking cows, as the milking herd represented the only cows subject to confinement and therefore waste collection. Second, the total amount of waste produced in confinement was calculated based on the proportion of time spent in confinement. Finally, values for the percentage of loafing lot waste collected were used to calculate the amount of waste available to be spread on pasture and cropland (Table 3.5). Stored waste was spread on pastureland. It was assumed that 100% of land-applied waste is available for transport in surface runoff transport unless the waste is incorporated in the soil by plowing during seedbed preparation. Percentage of cropland plowed and amount of waste incorporated was adjusted using calibration for the months of planting.

4.3.3.2 Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled “Modeling Cattle Stream Access” conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for VADCR. The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse and goat) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture landuse type was area-weighted.

4.3.3.3 Direct Deposition to Streams

Beef and dairy cattle are the primary sources of direct deposition by livestock in the Back Creek watershed. The amount of waste deposited in streams each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the "stream access" landuse, 30% of the waste was modeled as being directly deposited in the stream and 70% remained on the land segment adjacent to the stream. The 70% remaining was treated as manure deposited on land. However, applying it in a separate land-use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

4.3.4 Biosolids

Investigation of VDH data indicated that biosolids applications have occurred within the Back Creek watershed. For model calibration, biosolids were modeled at the average reported load, and average fecal coliform density. With urban populations growing, the disposal of biosolids will take on increasing importance. Class B biosolids have been measured with 68,467 cfu/g-dry and are permitted to contain up to 1,995,262 cfu/g-dry, as compared with approximately 240 cfu/g-dry for dairy waste. The sensitivity analysis (see Section 4.6) provided insight into the effects that increased applications of biosolids could have on water quality. During allocation runs, biosolids applications were modeled at the highest permittable loading rate (*i.e.*, 15 dry tons/ac at 1,995,262 cfu/g) applied to all permitted acreages in the month of May each year.

4.3.5 Wildlife

For each species, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.2.5). An example of one of these layers is shown in Figure 4.2. This layer was overlaid with the landuse layer and the resulting area was calculated for each landuse in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the waste load, fecal coliform densities, and number of animals for each species.

Seasonal distribution of waste was determined using seasonal food preferences for deer and turkey. Goose and duck populations were varied based on migration patterns, but the load available for delivery to the stream was never reduced below 40% of the maximum to account for the resident population of birds. No seasonal variation was assumed for the remaining species. For each species, a portion of the total waste load was considered to be land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.14). It was estimated, for all animals other than beaver, that 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term (1995–2008) projections were made to wildlife populations, as there was no available data to support such adjustments.

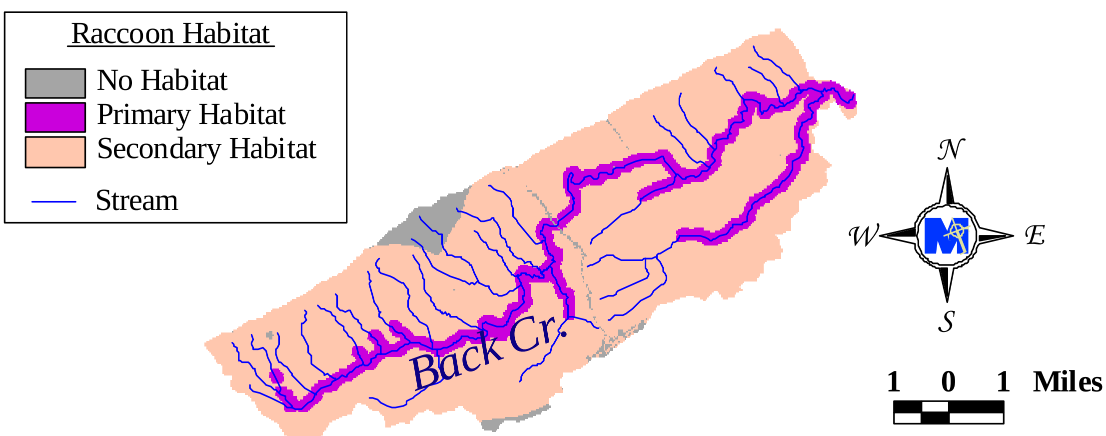


Figure 4.2 Example of raccoon habitat layer developed by MapTech in the Back Creek watershed.

4.3.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals/house), waste load, and fecal coliform density are reported in Section 3.2.6. Waste from pets was distributed in the residential landuses. The location of households was taken from the 1990 and 2000 Census (USCB, 1990, 2000). The landuse and household layers were overlaid, which resulted in number of households per landuse. The number of animals per landuse was determined by multiplying the number of households by the population density. The amount of fecal coliform deposited daily by pets in each landuse segment was calculated by multiplying the waste load, fecal coliform density, and number of animals for both cats and dogs. The waste load was assumed not to vary seasonally. The populations of cats and dogs were projected from 1990 data to 1995, 2003, and 2008 based on housing growth rates.

4.4 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.*, stream geometry and resistance to flow). In order to determine a representative stream profile for each stream reach, cross-sections were surveyed at the subwatershed outlets. One outlet was considered the beginning of the next reach, when appropriate. In the case of a confluence, sections were surveyed above the confluence for each tributary and below the confluence on the main stream.

Most of the sections exhibited distinct flood plains with pitch and resistance to flow significantly different from that of the main channel slopes. The streambed, channel banks, and flood plains were identified. Once identified, the streambed width and slopes of channel banks and flood plains were calculated using the survey data. A representative stream profile for each surveyed cross-section was developed and consisted of a trapezoidal channel with pitch breaks at the beginning of the flood plain (Figure 4.3). With this approach, the flood plain can be represented differently from the streambed. To represent the entire reach, profile data collected at each end of the reach were averaged.

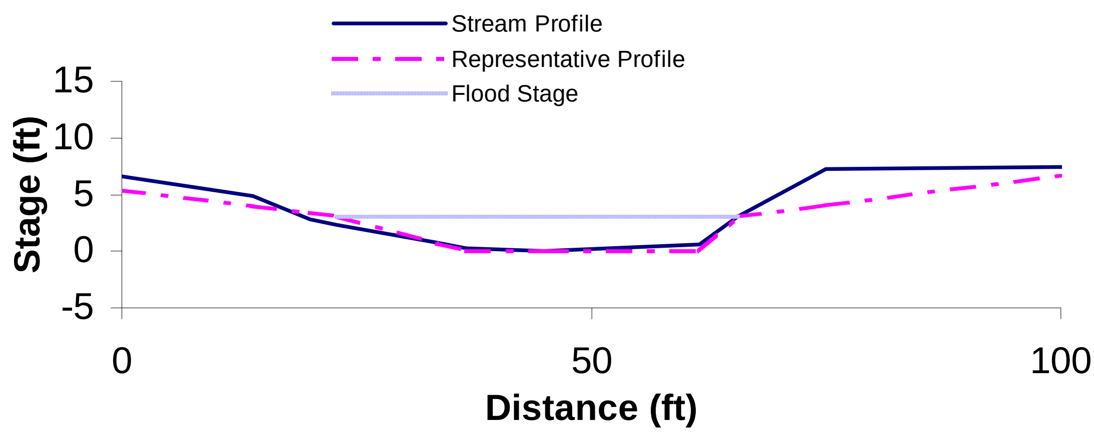


Figure 4.3 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with different values for resistance to flow (Manning's n) assigned to the flood plains and streambeds. The conveyance was calculated for each of the two flood plains and the main channel, then added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (in ft^3/s) at a given depth.

A key parameter used in the calculation of conveyance is the Manning's roughness coefficient, n. There are many ways to estimate this parameter for a section. The method first introduced by Cowan (1956) and adopted by the Soil Conservation Service (1963) was used to estimate Manning's n. This procedure involves a 6-step process of evaluating the properties of the reach, which is explained in more detail by Chow (1959). Field data describing the channel bed, bank stability, vegetation, obstructions, and other pertinent parameters were collected and photographs were taken of the stream sections. Once the field data were collected, they were used to estimate the Manning's roughness for the section observed. The pictures were compared to pictures reported in Chow (1959) for validation of the estimates of the Manning's n for each section.

The result of the field inspections of the reach sections was a set of characteristic slopes (channel sides and field plains), bed widths, heights to flood plain, and Manning's roughness coefficients. Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from Digital Elevation Models (DEMs) and a stream-flow network digitized from USGS 7.5-minute quadrangle maps (scale 1:24,000). These data were used to derive the Hydraulic Function Tables (F-tables) used by the HSPF model (Table 4.5). The F-tables consist of four columns; depth (ft), area (ac), volume (ac-ft), and outflow (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. A maximum depth of 50 ft was used in the F-tables. The area represents the surface area of the flow in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second.

Table 4.5 Example of an "F-table" calculated for the HSPF model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0.0	0.00	0.00	0.00
0.2	21.96	4.37	10.87
0.4	22.16	8.78	34.54
0.6	22.36	13.23	67.92
0.8	22.56	17.73	109.75
1.0	22.77	22.26	159.29
1.3	23.07	29.14	246.88
1.7	23.48	38.44	386.59
2.0	23.78	45.53	507.43
2.3	24.08	52.71	641.30
2.7	24.49	62.43	839.20
3.0	24.79	69.82	1,001.68
6.0	29.42	149.62	3,222.35
9.0	37.08	249.37	6,254.60
12.0	44.73	372.08	10,078.05
15.0	52.38	517.75	14,818.37
25.0	77.32	1,163.48	38,629.43
50.0	92.02	2,796.19	103,246.75

4.5 Selection of Representative Modeling Period

Selection of the representative modeling periods was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrological conditions. Modeling periods were selected for hydrology calibration/validation, water quality calibration/validation, and modeling of allocation scenarios. Special Study data (*i.e.*, instantaneous flow values) at USGS Station #03171400 (Neck Creek at Route 617 near Belspring, VA) were available from 1982 to 1984, while data from USGS Stations #03171350 (Back Creek at Route 100, near Highland, VA), and #03171405 (Back Creek At Route 600, near Parrot, VA) were available from 2002 to 2003. Due to the sparse amount of data (*i.e.*, 16 observations at three locations over two 2-year periods), a paired watershed approach was used to set initial parameters for the model, and all available data were used for the hydrology calibration. Water quality data (*i.e.*, fecal coliform concentrations) were available from 1992 through 2003, with more data available in the 2001 to 2003 timeframe. A representative period for water quality calibration and validation was selected with consideration for the hydrology calibration period, availability of water quality data, and the VADEQ assessment period from July 1992 through June 1997 that led to the inclusion of the Back Creek segment on the 1998 Section 303 (d) list. With these criteria in mind, the modeling periods for water quality calibration and validation were 10/1/93 through 9/30/98 and 10/1/98 through 9/30/2003, respectively.

The period selected for modeling of allocation scenarios represents critical hydrological conditions. The mean daily precipitation for each season was calculated for the period October 1970 through September 2000. This resulted in 30 observations of mean precipitation for each season. The mean and variance of these observations were calculated. Next, a representative period for modeling was chosen and compared to the historical data. The representative period was chosen such that the mean and variance of each season in the modeled period was not significantly different from the historical data (Table 4.6, Figure 4.4, and Figure 4.5).

Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The resulting period for modeling of allocation scenarios was 10/1/1986 through 9/30/1991.

Table 4.6 Comparison of modeled period to historical records.

	Precipitation (in/day)			
	Fall	Winter	Spring	Summer
	Historical Record (1981-1996)			
Mean	0.0905	0.1002	0.1097	0.1113
Variance	0.0008	0.0015	0.0006	0.0013
	Representative Hydrological Period (10/1/86-9/30//91)			
Mean	0.0961	0.0852	0.0975	0.1110
Variance	0.0008	0.0017	0.0005	0.0032
	p-Values			
Mean	0.3487	0.2416	0.1592	0.4954
Variance	0.4289	0.3685	0.5124	0.0832

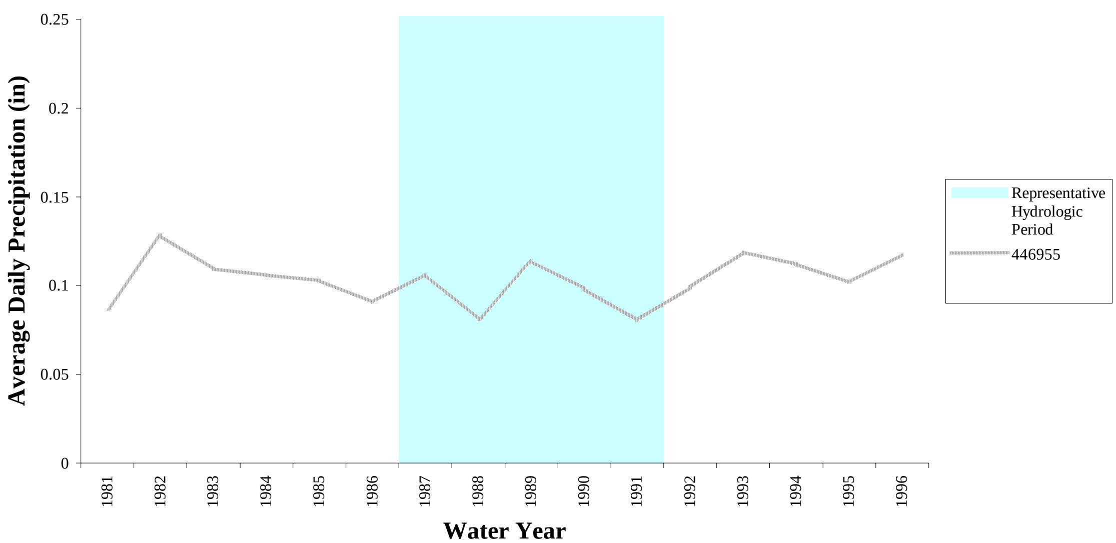


Figure 4.4 Annual Historical Precipitation (Station 446955) Data.

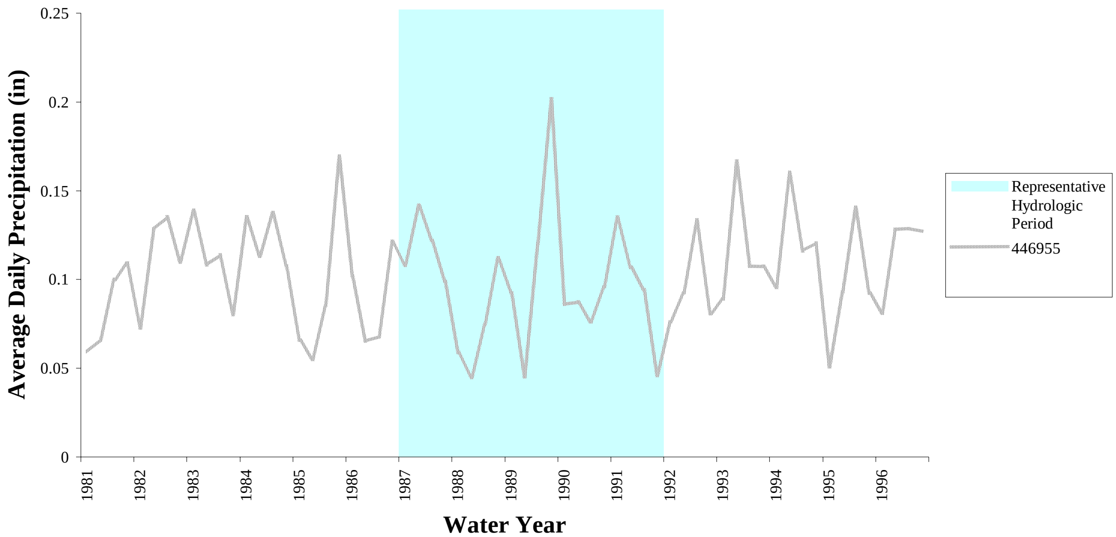


Figure 4.5 Seasonal Historical Precipitation (Station 446955) Data.

4.6 Sensitivity Analysis

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads). Additional analyses were performed to define the sensitivity of the modeled system to growth or technology changes that impact waste production rates.

Sensitivity analyses were run on both hydrologic and water quality parameters. The parameters adjusted for the hydrologic sensitivity analysis are presented in Table 4.7, with base values for the model runs given. The parameters were adjusted to -50%, -10%, 10%, and 50% of the base value, and the model was run for water years 1981 through 1985. Where an increase of 50% exceeded the maximum value for the parameter, the maximum value was used and the parameters increased over the base value were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliforms from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration) and UZSN (Upper Zone Storage), which governs surface transport, and to a lesser extent by LZSN (Lower Zone Storage), and LZETP (Lower Zone Evapotranspiration), which affect soil moisture. Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows (as evidenced by their influence in the *Low Flows* and *Summer Flow Volume* statistics) were AGWRC (Groundwater Recession Rate), INFILT, CEPSC (interception), DEEPFR (Losses to Deep Aquifers) and, to a lesser extent, BASETP (Evapotranspiration from Base Flow). The responses of these and other hydrologic outputs are reported in Table 4.8.

For the water quality sensitivity analysis, an initial base run was performed using precipitation data from water years 1993 through 1998 and model parameters established for 1995 conditions. The three parameters impacting the model's water quality response (Table 4.9) were increased and decreased by amounts that were consistent with the range of values for the parameter.

Since the water quality standard for *E. coli* bacteria is based on concentrations rather than loadings, it was considered necessary to analyze the effect of source changes on the monthly geometric-mean *E. coli* concentration. A monthly geometric mean was calculated for all months during the simulation period, and the value for each month was averaged. Deviations from the base run are given in Table 4.10 and plotted by month in Figure 4.6 through Figure 4.8.

In addition to analyzing the sensitivity of the model response to changes in model parameters, the response of the model to changes in land-based and direct loads was analyzed. The impacts of land-based and direct load changes on the annual load are presented in Figure 4.9, while impacts on the monthly geometric mean are presented in Figure 4.10 and Figure 4.11.

Table 4.7 Base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
AGWRC	Active Groundwater Coefficient	1/day	0.989-0.994
BASETP	Base Flow Evapotranspiration	---	0.0315-0.0325
MON-INT	Interception Storage Capacity	in	0.01 – 0.40
DEEPFR	Fraction of Deep Groundwater	---	0.0
INFILT	Soil Infiltration Capacity	in/hr	0.006-0.296
INTFW	Interflow Inflow	---	1.0
KVARY	Groundwater Recession Coefficient	1/day	0.05-0.12
LZSN	Lower Zone Nominal Storage	in	2.0-3.0
MON-LZETPARM	Monthly Lower Zone Evapotranspiration	---	0.1-0.9
NSUR	Manning's *n* for Overland Flow	---	0.1-0.48
UZSN	Upper Zone Storage Capacity	in	0.05-2.0

Table 4.8 Sensitivity analysis results for hydrologic model parameters.

Model Parameter	Parameter Change (%)	Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC	-50	1.92%	165.46%	-88.78%	14.10%	-18.09%	-15.58%	26.30%	69.11%
AGWRC	-10	0.94%	61.11%	-51.53%	10.95%	-14.34%	-17.01%	22.94%	64.92%
AGWRC[1]	1	-28.12%	-26.94%	-27.59%	-32.80%	-31.93%	-16.88%	-28.26%	-7.78%
BASETP	-50	1.17%	-1.28%	2.84%	-0.20%	2.84%	3.06%	-0.84%	-1.88%
BASETP	-10	0.23%	-0.28%	0.57%	-0.05%	0.56%	0.59%	-0.16%	-0.45%
BASETP	10	-0.23%	0.29%	-0.58%	0.05%	-0.57%	-0.60%	0.18%	0.54%
BASETP	50	-1.11%	1.52%	-2.93%	0.21%	-2.84%	-2.97%	0.98%	3.47%
DEEPFR	-50	5.41%	4.29%	5.81%	5.33%	5.55%	5.39%	5.38%	5.17%
DEEPFR	-10	1.08%	0.86%	1.16%	1.06%	1.11%	1.08%	1.08%	0.97%
DEEPFR	10	-1.08%	-0.85%	-1.16%	-1.06%	-1.11%	-1.08%	-1.07%	-0.98%
DEEPFR	50	-5.41%	-4.25%	-5.83%	-5.31%	-5.55%	-5.42%	-5.37%	-5.13%
INFILT	-50	-0.73%	38.94%	-12.28%	0.33%	-9.07%	-1.51%	8.39%	8.91%
INFILT	-10	-0.26%	4.10%	-1.42%	-0.32%	-1.15%	-0.16%	0.77%	0.25%
INFILT	10	0.29%	-3.01%	1.12%	0.39%	0.99%	0.14%	-0.52%	-0.11%
INFILT	50	1.59%	-8.95%	4.05%	2.15%	4.36%	0.64%	-1.44%	0.71%
INTFW	-50	-0.39%	-2.52%	0.55%	-0.63%	-0.15%	-0.68%	-0.08%	-1.57%
INTFW	-10	-0.05%	-0.36%	0.08%	-0.07%	-0.02%	-0.10%	-0.01%	-0.18%
INTFW	10	0.04%	0.31%	-0.07%	0.05%	0.02%	0.09%	0.01%	0.15%
INTFW	50	0.16%	1.21%	-0.27%	0.19%	0.08%	0.36%	0.03%	0.60%
LZSN	-50	2.09%	12.14%	-0.97%	4.14%	-0.35%	-0.87%	5.14%	5.88%
LZSN	-10	0.30%	1.61%	-0.19%	0.67%	0.07%	-0.22%	0.59%	1.22%
LZSN	10	-0.27%	-1.38%	0.17%	-0.61%	-0.11%	0.19%	-0.46%	-1.04%
LZSN	50	-1.14%	-5.31%	0.62%	-2.58%	-0.77%	0.76%	-1.54%	-4.48%
MON-INTERCEP	-50	3.85%	-2.45%	7.13%	1.95%	5.60%	6.74%	1.49%	-0.23%
MON-INTERCEP	-10	0.66%	-0.66%	1.35%	0.29%	1.09%	1.22%	0.12%	-0.13%
MON-INTERCEP	10	-0.61%	0.69%	-1.28%	-0.28%	-1.09%	-1.02%	-0.10%	0.01%
MON-INTERCEP	50	-2.62%	3.57%	-5.98%	-1.02%	-4.89%	-4.89%	0.12%	1.78%
MON-LZETP	-50	11.64%	18.57%	15.22%	7.78%	4.67%	13.12%	23.23%	3.76%
MON-LZETP	-10	1.89%	2.11%	2.97%	1.40%	0.77%	1.78%	3.91%	0.31%
MON-LZETP	10	-1.53%	-1.45%	-2.52%	-1.06%	-0.57%	-1.47%	-3.28%	0.02%
MON-LZETP	50	-7.10%	-5.74%	-11.66%	-4.33%	-3.51%	-9.08%	-12.92%	0.43%
MON-MANNING	-50	0.12%	1.59%	-0.18%	-0.09%	0.03%	0.41%	0.22%	0.33%
MON-MANNING	-10	0.02%	0.21%	-0.02%	-0.02%	0.00%	0.05%	0.04%	0.04%
MON-MANNING	10	-0.01%	-0.17%	0.02%	0.01%	0.00%	-0.05%	-0.03%	-0.04%
MON-MANNING	50	-0.06%	-0.71%	0.08%	0.05%	0.00%	-0.20%	-0.12%	-0.16%
MON-UZSN	-50	4.80%	17.20%	0.88%	4.29%	7.29%	8.95%	-1.31%	10.48%
MON-UZSN	-10	0.68%	2.59%	0.02%	0.58%	1.24%	1.65%	-0.76%	1.27%
MON-UZSN	10	-0.58%	-2.19%	0.01%	-0.48%	-1.09%	-1.50%	0.77%	-1.32%
MON-UZSN	50	-2.11%	-8.13%	0.06%	-1.90%	-4.14%	-6.60%	4.14%	-4.50%

[1]Maximum value used corresponds to the maximum allowable value for the parameter.

Table 4.9 Base parameter values used to determine water quality model response.

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	0.0E+00 – 2.9E+11
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	1.00
FSTDEC	In-stream First Order Decay Rate	1/day	1.15

Table 4.10 Percent change in average monthly *E. coli* geometric mean for the years 1993-1998.

Model	Parameter Change	Percent Change in Average Monthly *E. coli* Geometric Mean											
Parameter	(%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	37.16	33.10	37.60	42.76	46.05	47.54	50.96	52.75	54.29	52.58	50.57	43.07
FSTDEC	-10	5.73	5.22	5.82	6.41	6.78	6.92	7.24	7.39	7.48	7.32	7.20	6.31
FSTDEC	10	-5.14	-4.72	-5.22	-5.69	-5.98	-6.09	-6.33	-6.43	-6.48	-6.37	-6.30	-5.57
FSTDEC	50	-21.31	-19.84	-21.65	-23.24	-24.21	-24.52	-25.26	-25.54	-25.64	-25.30	-25.16	-22.61
SQOLIM	-50	-14.84	-12.16	-9.91	-7.56	-9.89	-9.68	-7.54	-3.51	-5.11	-5.85	-8.73	-6.66
SQOLIM	-25	-5.38	-4.41	-3.39	-4.52	-4.41	-3.36	-1.59	-2.22	-2.65	-4.10	-3.05	
SQOLIM	50	11.00	8.30	7.41	6.02	8.04	5.72	3.48	1.99	3.92	4.85	7.55	5.23
SQOLIM	100	20.64	16.83	12.84	9.61	13.86	18.26	14.29	6.09	6.40	8.61	12.74	8.79
WSQOP	-50	20.22	18.91	14.09	10.96	12.89	12.35	9.08	4.13	7.42	8.03	10.54	9.30
WSQOP	-10	2.65	2.45	1.87	1.43	1.72	1.65	1.27	0.56	0.97	1.07	1.43	1.21
WSQOP	10	-2.28	-2.10	-1.62	-1.22	-1.48	-1.43	-1.12	-0.49	-0.83	-0.92	-1.25	-1.04
WSQOP	50	-8.97	-8.21	-6.41	-4.81	-5.88	-5.66	-4.51	-1.96	-3.29	-3.65	-4.98	-4.08

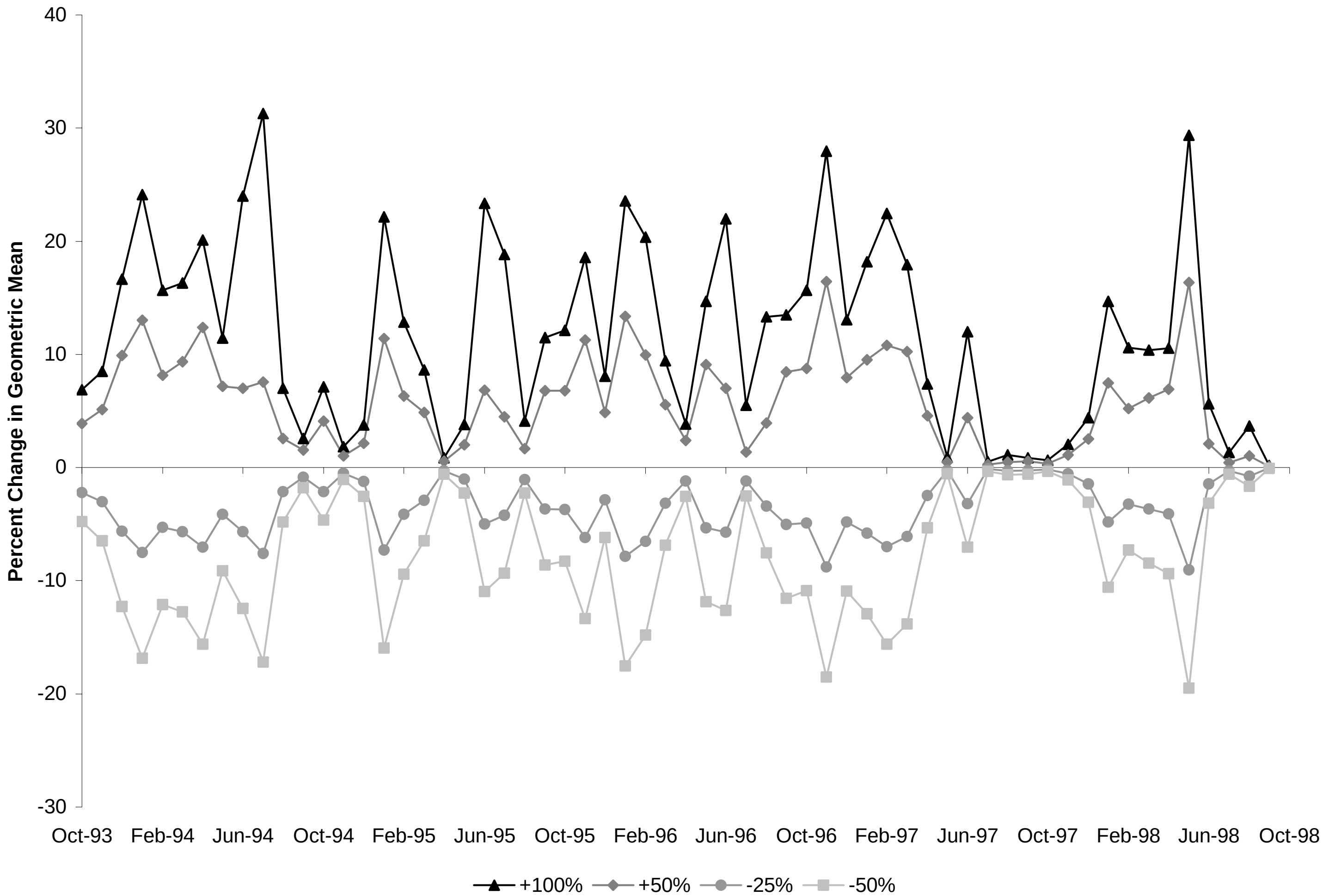


Figure 4.6 Results of sensitivity analysis on monthly geometric-mean concentrations in the Back Creek watershed, as affected by changes in maximum FC accumulation on land (MON-SQOLIM).

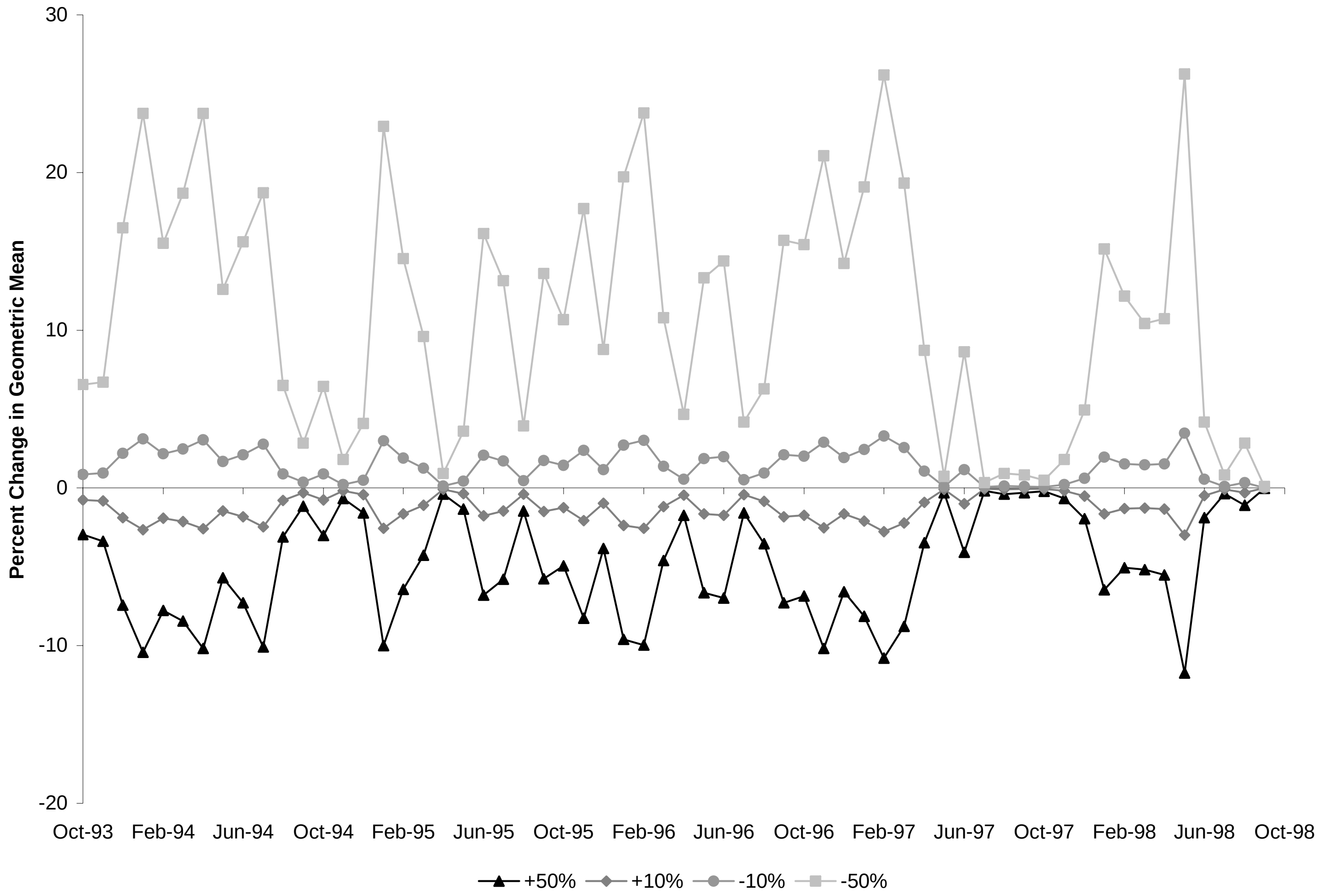


Figure 4.7 Results of sensitivity analysis on monthly geometric-mean concentrations in the Back Creek watershed, as affected by changes in the wash-off rate for FC fecal coliform on land surfaces (WSQOP).

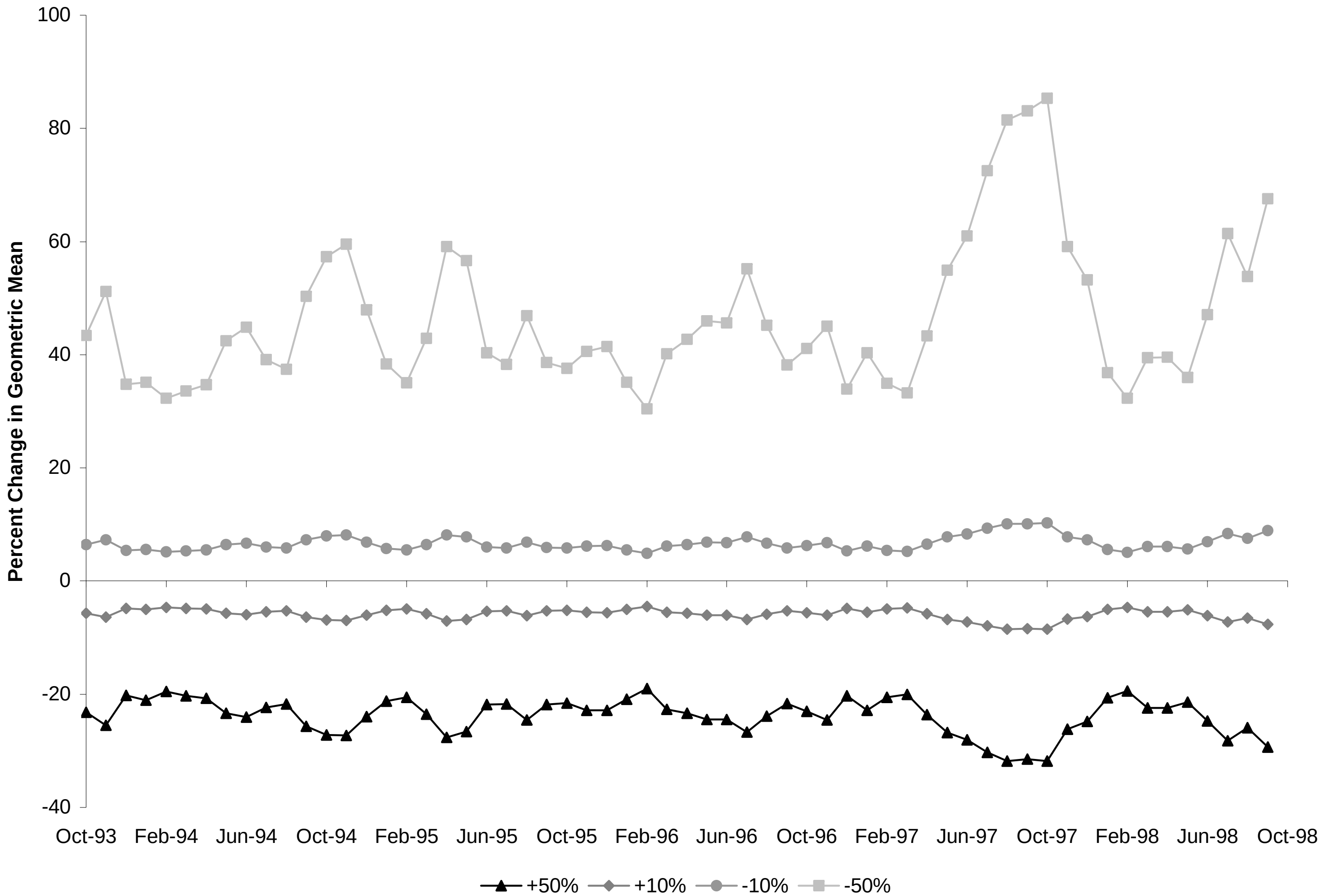


Figure 4.8 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Back Creek watershed, as affected by changes in the in-stream first-order decay rate (FSTDEC).**

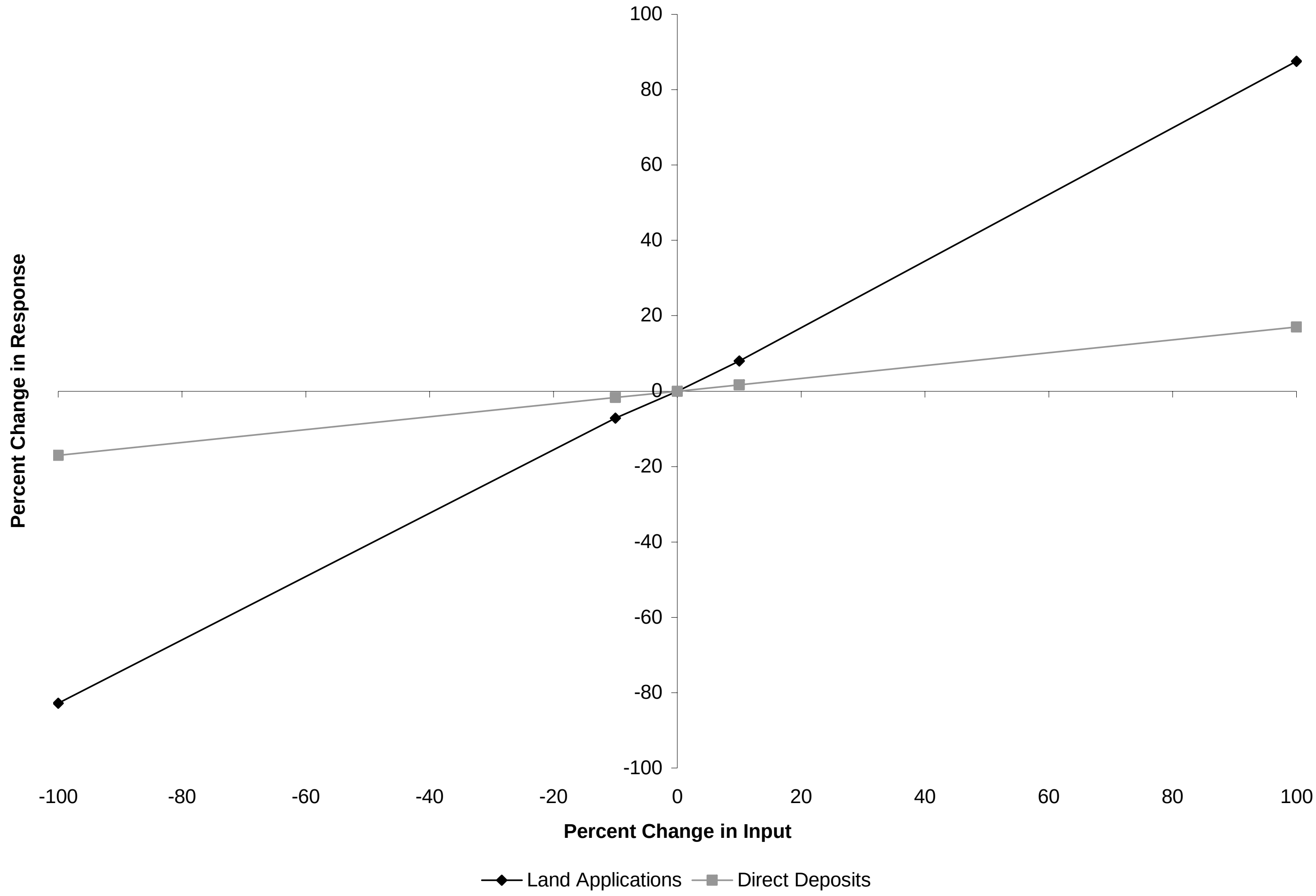


Figure 4.9 Total loading sensitivity to changes in direct and land-based loads for the Back Creek watershed.

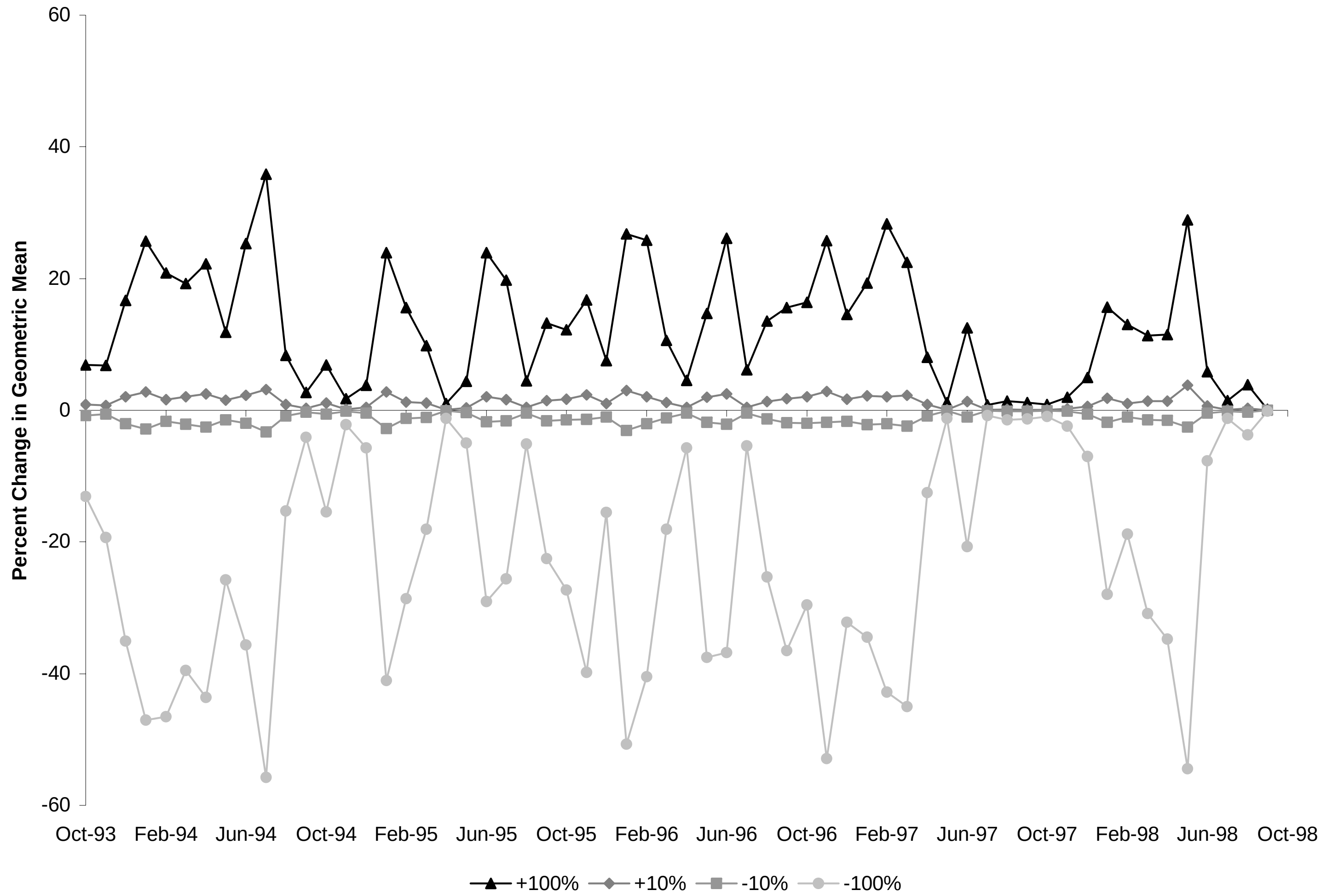


Figure 4.10 Results of sensitivity analysis on monthly geometric-mean concentrations in the Back Creek watershed, as affected by changes in land-based loadings.

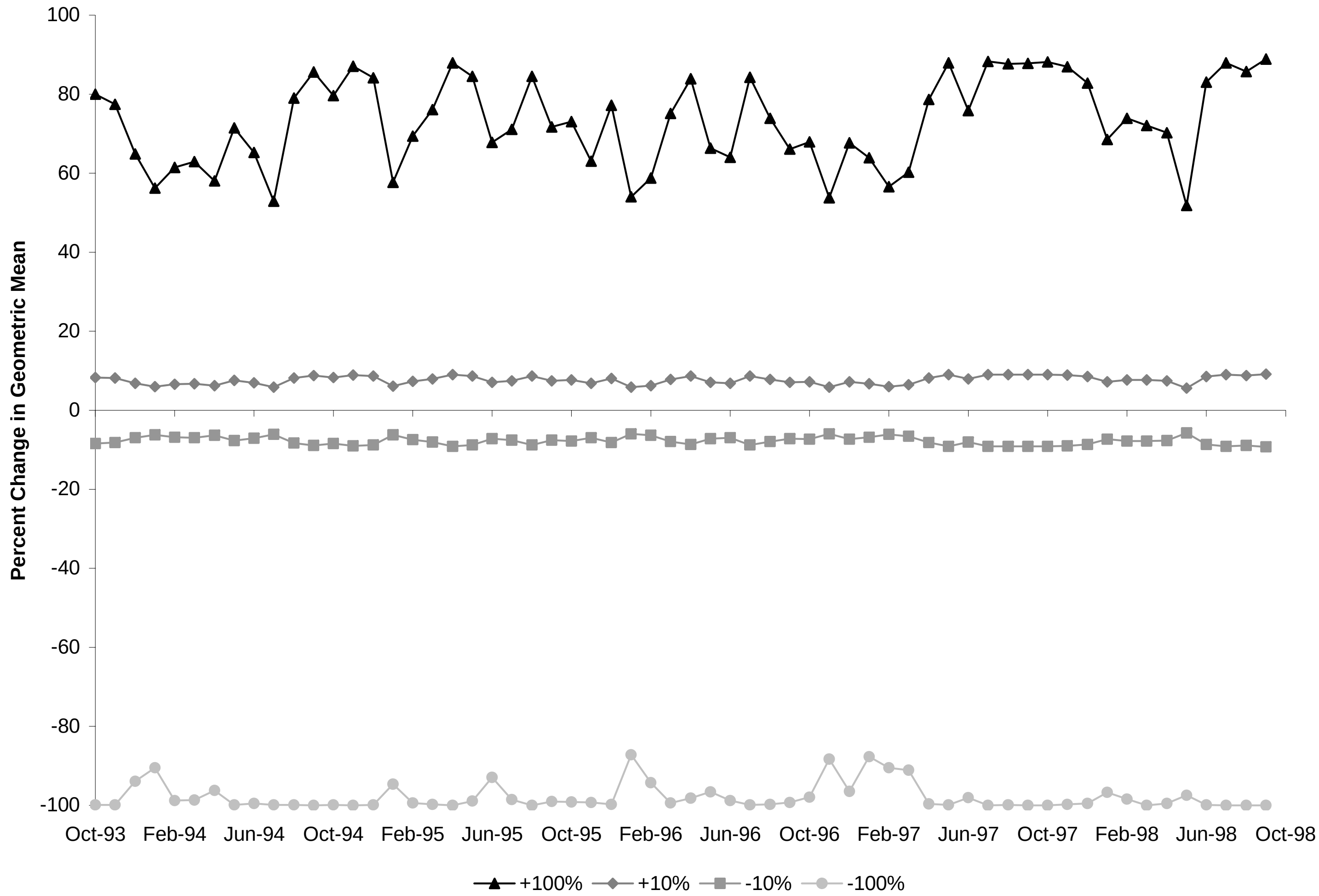


Figure 4.11 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Back Creek watershed, as affected by changes in loadings from direct nonpoint sources.**

4.7 Model Calibration and Validation Processes

Calibration and validation are performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on a paired watershed analysis, with consideration for available soils, landuse, and topographic data. Qualities of fecal coliform sources were modeled as described in chapters 3 and 4. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Validation is the process of comparing modeled data to observed data during a period other than that used for calibration. During validation, no adjustments are made to model parameters. The goal of validation is to assess the capability of the model in hydrologic conditions other than those used during calibration.

4.7.1 Hydrologic Calibration and Validation

Due to the lack of continuous stream flow data for Back Creek, the paired watershed approach, with additional refinement using instantaneous flow measurements was used to calibrate the HSPF model. Through this approach, the HSPF model is calibrated using data from a hydrologically similar watershed, where continuous stream flow is available. The calibrated parameters from the model (*e.g.*, lower zone storage), in conjunction with physically derived parameters (*e.g.*, land slope and slope length) specific to Back Creek, are then used as an initial representation of the watershed. In the case of Back Creek, this representation was then refined through calibration to instantaneous flow measurements collected primarily during base-flow conditions.

Upper Tinker Creek was compared to the Back Creek watershed and chosen as an appropriate watershed for a paired-watershed calibration. The hydrologic comparison of the watersheds was established by examining the landuse distribution, total drainage area, channel and watershed characteristics, and hydrologic soil group.

The first action taken to implement the paired watershed was examining the similarities between the Upper Tinker Creek and Back Creek watersheds. The landuse distribution is shown in Table 4.11. The four landuse categories were agricultural, urban, natural and other. The agricultural landuses category included barren land, pasture, cropland, and livestock access areas, which accounted for 56% of the Upper Tinker Creek watershed and 57% of the Back Creek watershed.

Table 4.11 Landuse distribution for Back Creek and Upper Tinker Creek watersheds.

Landuse Categories	Landuse	Back Creek		Upper Tinker Creek	
		acres	%	acres	%
Agricultural	Barren	22	0.09	23	0.31
	Cropland/Row Crops	1,337	5.25	78	1
	Livestock Access	702	2.76	276	3.7
	Pasture	12,344	48.49	3,793	50.8
Total Agricultural		**14,405**	**56.59**	**4,170**	**55.8**
Urban	Commercial	131	0.52	4	0.05
	Residential	38	0.15	91	1.2
Total Urban		**169**	**0.67**	**95**	**1.3**
Natural	Forest and Wetlands	10,868	42.70	3,173	42.5
Other	Water	13	0.05	30	0.41
Total		**25,456**	**100**	**7,468**	**100**

The soil hydrologic groups in both watersheds were examined. The soils series present in both the Upper Tinker Creek and Back Creek watersheds consists of well-drained soils. Based on the hydrologic soil group classification, the soil series present in the two watersheds predominantly range from “B” to “C” (Table 4.12).

Table 4.12 Soil distribution in Tinker Creek and Back Creek.

Statsco ID	Hydrologic Soil Group	Percent of Watershed	
		Tinker Creek	Back Creek
VA001	B	0%	21%
VA002	B/C	50%	46%
VA003	B/C	40%	19%
VA004	C	0%	14%
VA005	B/C	10%	0%

Additional watershed characteristics of Tinker Creek and Back Creek, including the drainage area, main channel slope, main channel length, and the drainage density, were compared. The data, presented in Table 4.13, indicates that these physical characteristics of the watershed are similar.

Table 4.13 Comparison of Tinker Creek and Back Creek Watershed Characteristics.

Watershed	Drainage Area (acre)	Main Channel Slope	Main Channel Length (ft)	Drainage Density (ft/acre)
Tinker Creek	7482	0.08	2162	14
Back Creek	25511	0.11	18591	10

Based on the landuse distribution, soil types, and the watershed physical characteristics, the Upper Tinker Creek watershed is hydrologically similar to the Back Creek watershed. The HSPF model was calibrated and validated for the Upper Tinker Creek watershed (VADEQ, 2003), where continuous flow data was available. The HSPF input parameters for Upper Tinker Creek watershed were used as base input parameters for Back Creek when calibrating Back Creek with the base flow values from USGS station #03171350 (Back Creek at Route 100, near Highland, VA), #03171400 (Neck Creek at Route 617 near Belspring, VA), and #03171405 (Back Creek At Route 600, near Parrot, VA). Parameters that were adjusted during the hydrologic calibration represented the amount of evapotranspiration from the root zone (MON-LZETP), the recession rates for groundwater (AGWRC), the amount of soil moisture storage in the upper zone (MON-UZS) and lower zone (MON-LZE), the infiltration capacity (INFILT), baseflow PET (BASETP), forest coverage (FOREST), and Manning’s n for overland flow plane (MON-MAN). Table 4.14 contains the typical range for the above parameters along with the initial estimate and final calibrated value. Although HSPF is not a physically based model, and thus parameters are adjusted during calibration in order to match observed data, guidelines are provided by E.P.A as to typically encountered values. Final calibrated parameters did not go outside of typical values, except in the case of LZETP, which ranged just outside the high value of 0.9, with a peak value of 1.035 for the forest land-use during the summer months, which coincided with periods of lower than expected flows in the observed record. Specific values for each calibrated parameter are given in the excerpt from the calibrated UCI in Appendix C.

The model calibration results for Back Creek are presented in Figure 4.12 through Figure 4.14. The calibrated for hydrologic accuracy using instantaneous flow data from USGS Station #03171350 (Back Creek at Route 100, near Highland, VA), USGS Station #03171405 (Back Creek At Route 600, near Parrot, VA) and USGS Station #03171400 (Neck Creek at Route 617 near Belspring, VA). The distribution of flow volume between surface runoff, interflow, and groundwater was 8%, 22%, and 70%, respectively. While there were no peak flow values in the observed record to verify output during storm events, and only 15 observations in total, the model predicted base flow conditions well.

Table 4.14 Model parameters utilized for hydrologic calibration of Back Creek.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
FOREST	---	0.0 – 0.95	0.0	0.0 – 1.0
LZSN	in	2.0 – 15.0	2.0 – 3.0	2.0
INFILT	in/hr	0.001 – 0.50	0.006 – 0.296	0.151 – 0.248
LSUR	ft	100 – 700	100 – 700	100 – 800
SLSUR	---	0.001 – 0.30	0.001 – 0.155	0.001 – 0.182
KVARY	1/in	0.0 – 5.0	0.05 – 0.12	0.12
AGWRC	1/day	0.85 – 0.999	0.989 – 0.994	0.920 – 0.989
PETMAX	deg F	32.0 – 48.0	40.0	40.0
PETMIN	deg F	30.0 – 40.0	35.0	35.0
INFEXP	---	1.0 – 3.0	2.0	2.0
INFILD	---	1.0 – 3.0	2.0	2.0
DEEPFR	---	0.0 – 0.50	0.0	2.0 – 3.5
BASETP	---	0.0 – 0.20	0.0315 – 0.0325	0.0325
AGWETP	---	0.0 – 0.20	0.0	0.0
INTFW	---	1.0 – 10.0	1.0	1.0
IRC	1/day	0.30 – 0.85	0.3 – 0.85	0.3
MON-INT	in	0.01 - 0.40	0.01 – 0.40	0.01 – 0.40
MON-UZS	in	0.05 – 2.0	0.05 – 2.0	0.113 – 2.0
MON-LZE	---	0.1 – 0.9	0.1 – 0.9	0.1 – 0.9
MON-MAN		0.10 – 0.50	0.1 – 0.48	0.1 – 0.42
RETSC	in	0.0 – 1.0	0.1	0.1
KS	---	0.0 – 0.9	0.5	0.5

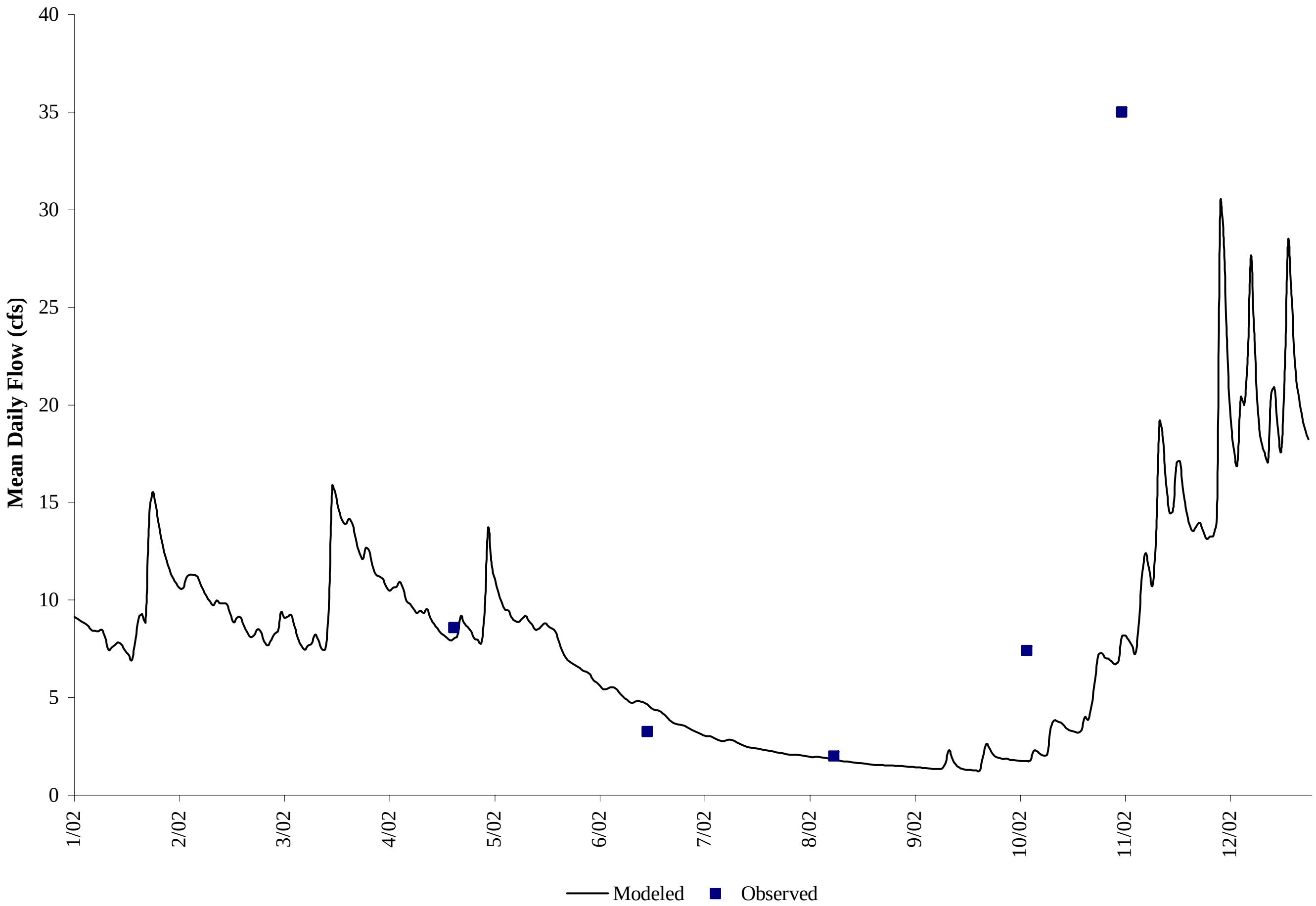


Figure 4.12 Calibration results for subwatershed 2 of Back Creek for the period 1/1/2002 through 12/31/2002.

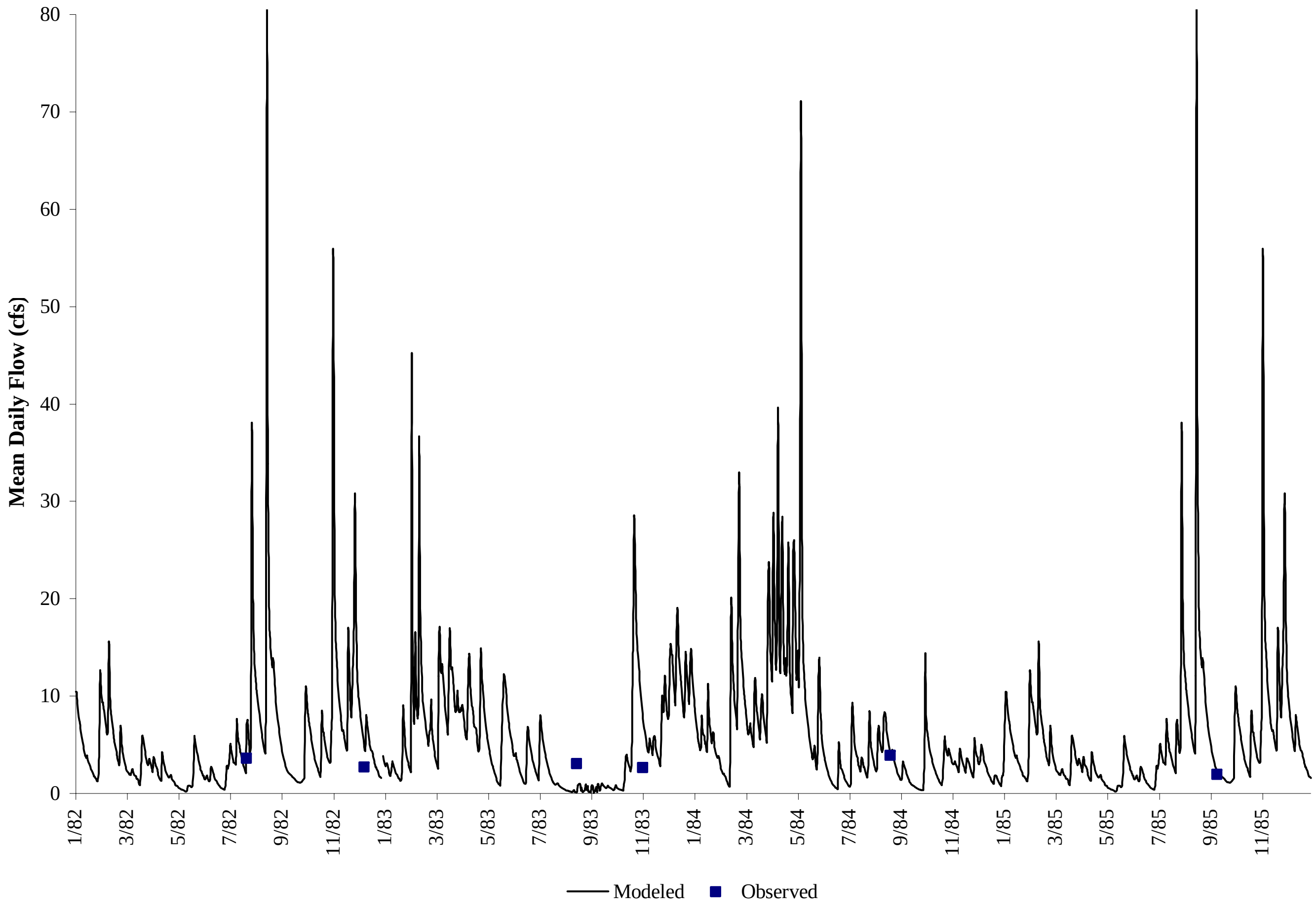


Figure 4.13 Calibration results for subwatershed 4 of Back Creek for the period 1/1/1982 through 12/31/1985.

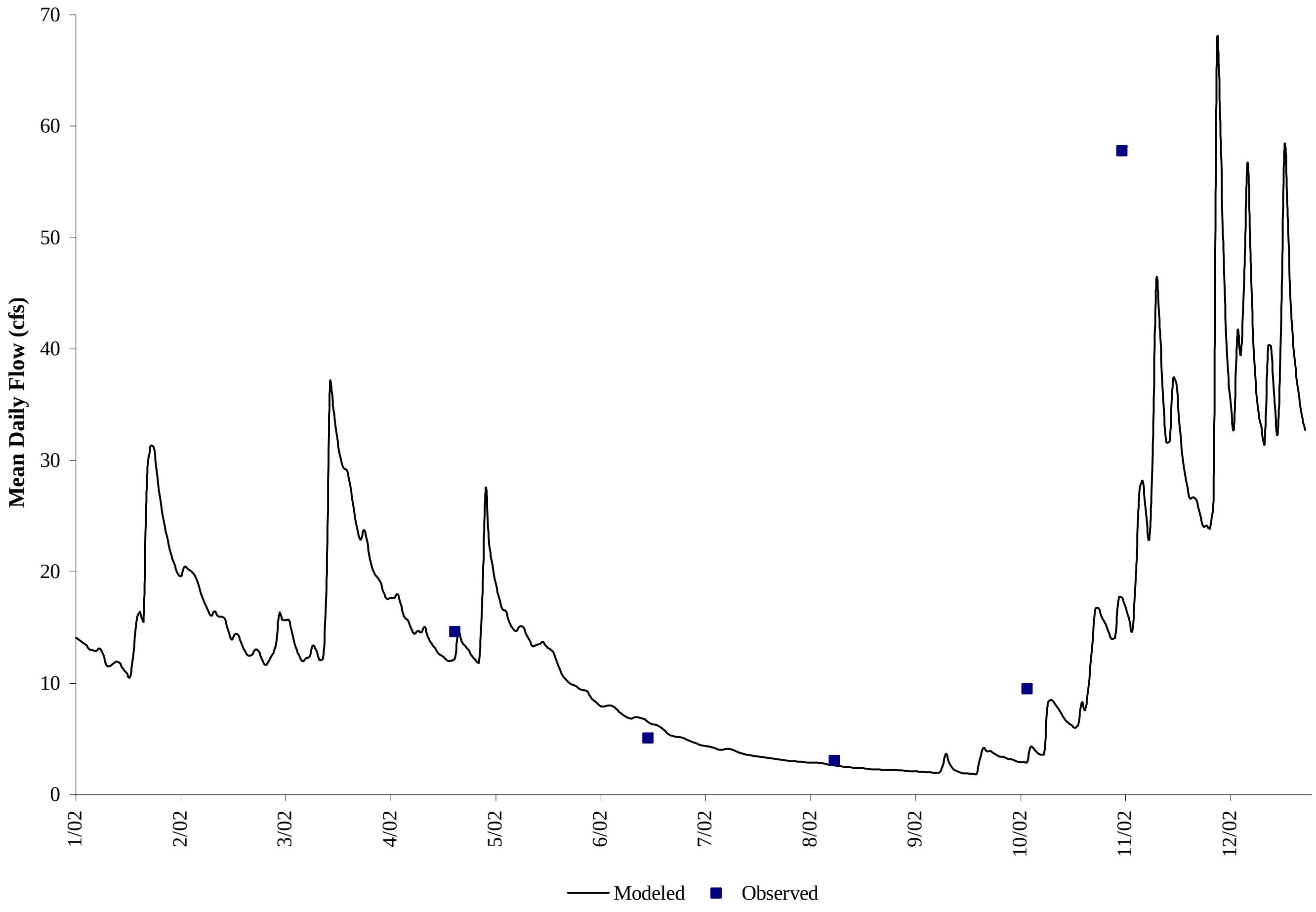


Figure 4.14 Calibration results for the outlet (subwatershed 5) of Back Creek for the 1/1/2002 through 12/31/2002.

4.7.2 Water Quality Calibration and Validation

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (*e.g.*, fecal coliform concentrations) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as fecal coliform concentration. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the limited amount of measured data for use in calibration and the practice of censoring both high (typically 8,000 or 16,000 cfu/100 ml) and low (under 100 cfu/100 ml) concentrations impede the calibration process.

The water quality calibration was conducted using monitored data from 10/1/93 through 9/30/98. Three parameters were utilized for model adjustment; in-stream first-order decay rate (FSTDEC), maximum accumulation on land (SQOLIM), and rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established (Table 4.15). Figure 4.15 shows the results of calibration. Modeled coliform levels matched observed levels during a variety of flow conditions, indicating that the model was well calibrated. Specific values for each calibrated parameter are given in the excerpt from the calibrated UCI in Appendix C.

Table 4.15 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
MON-ACCUM	FC/ac*day	0.0E+00 – 1.0E+20	0.0E+00 – 6.0E+10	0.0E+00 – 6.0E+10
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0E+00 – 2.9E+11	0.0E+00 – 3.0E+12
WSQOP	in/hr	0.05 – 3.00	1.00	0.01- 0.45
IOQC	FC/ft^3	0.0E+00 – 1.0E+06	0	0
AOQC	FC/ft^3	0 – 10	0	0
DQAL	FC/100ml	0 – 1,000	200	200
FSTDEC	1/day	0.01 – 10.00	1.15	.01
THFST	---	1.0 – 2.0	1.07	1.07

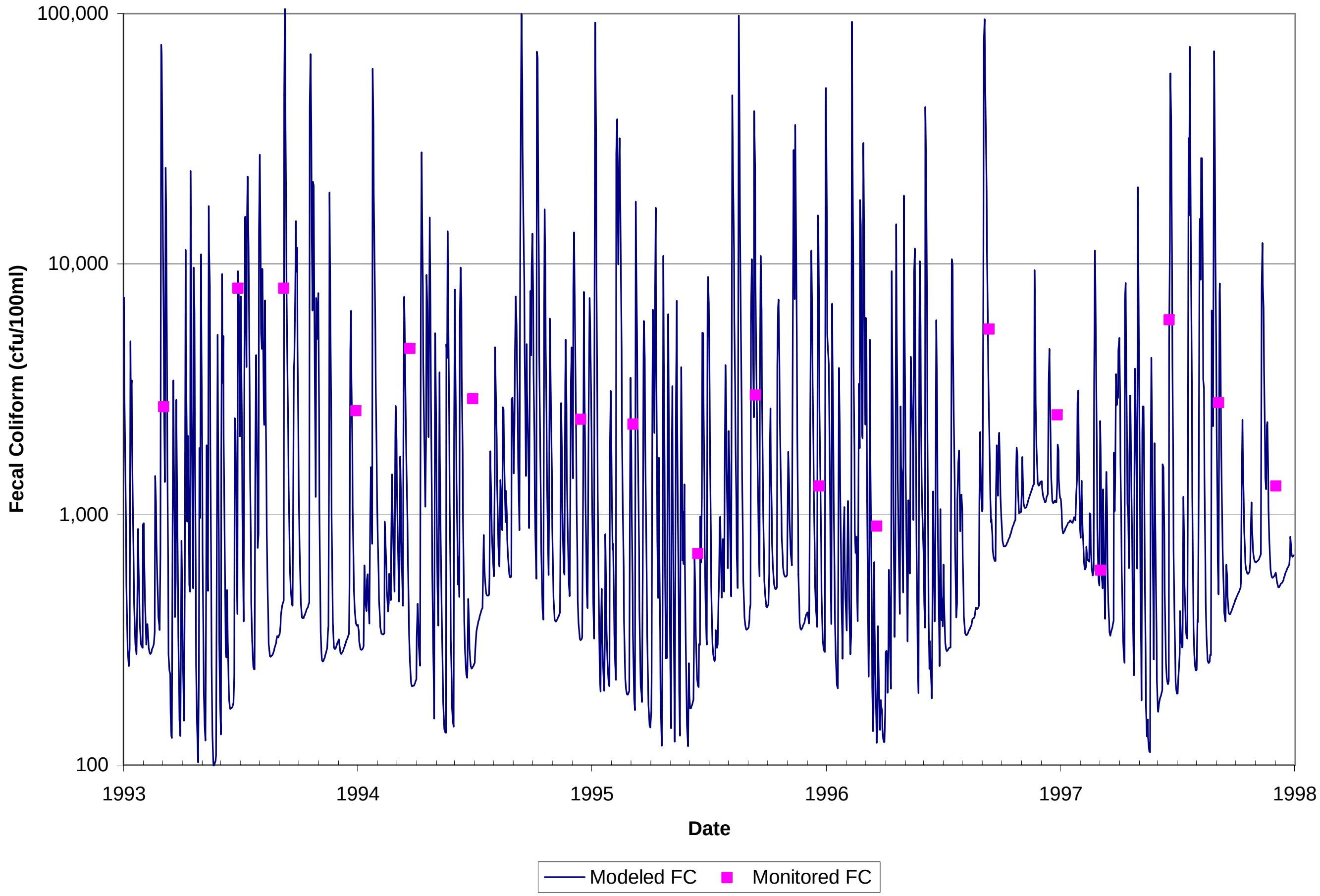


Figure 4.15 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 1 in the Back Creek impairment, during the calibration period.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2-day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2-day window} \end{aligned}$$

This 2-day window is considered to be a reasonable time frame to take into account the temporal variability in direct loadings from wildlife and livestock, and the spatial and temporal variability inherent in the use of point measurements of precipitation, and in the use of daily precipitation data. This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data and found to be at reasonable levels (Table 4.16).

Table 4.16 Results of analysis on calibration runs.

WQ Monitoring Station	Mean Standard Error (cfu/100 ml)	Maximum Simulated Value (cfu/100 ml)
9-BCK009.47	849.44[1]	224,320

[1]When adjusted for censored values, Mean Standard Error becomes 236.59.

The water quality validation was conducted using data for the time period from 10/1/98 to 9/20/03. The relationship between observed values and modeled values is shown in Figures 4.16 through 4.18. The results of standard error and maximum value analyses are reported in Table 4.17. Standard errors calculated from validation runs were comparable to standard errors calculated from calibration runs. Maximum simulated values were comparable to observed values in the area.

Table 4.17 Results of analyses on validation runs.

WQ Monitoring Station	Mean Standard Error (cfu/100 ml)	Maximum Simulated Value (cfu/100 ml)
9-BCK015.98	173.45	101,660
9-BCK009.47	442.12[1]	170,990
9-BCK000.74	113.99	123,170

[1] When adjusted for censored values, Mean Standard Error becomes 437.46.

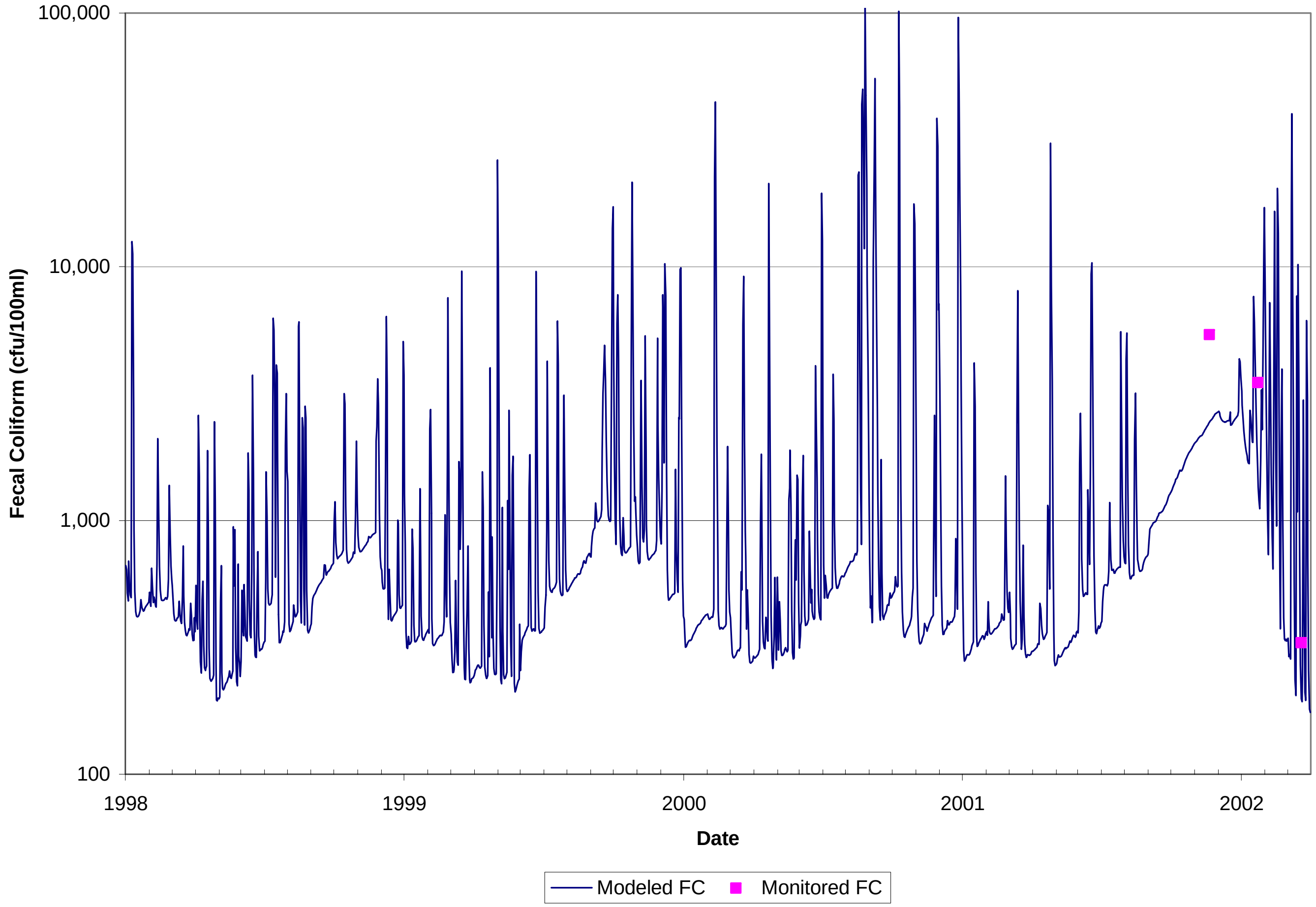


Figure 4.16 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 1 in the Back Creek impairment, during the validation period.

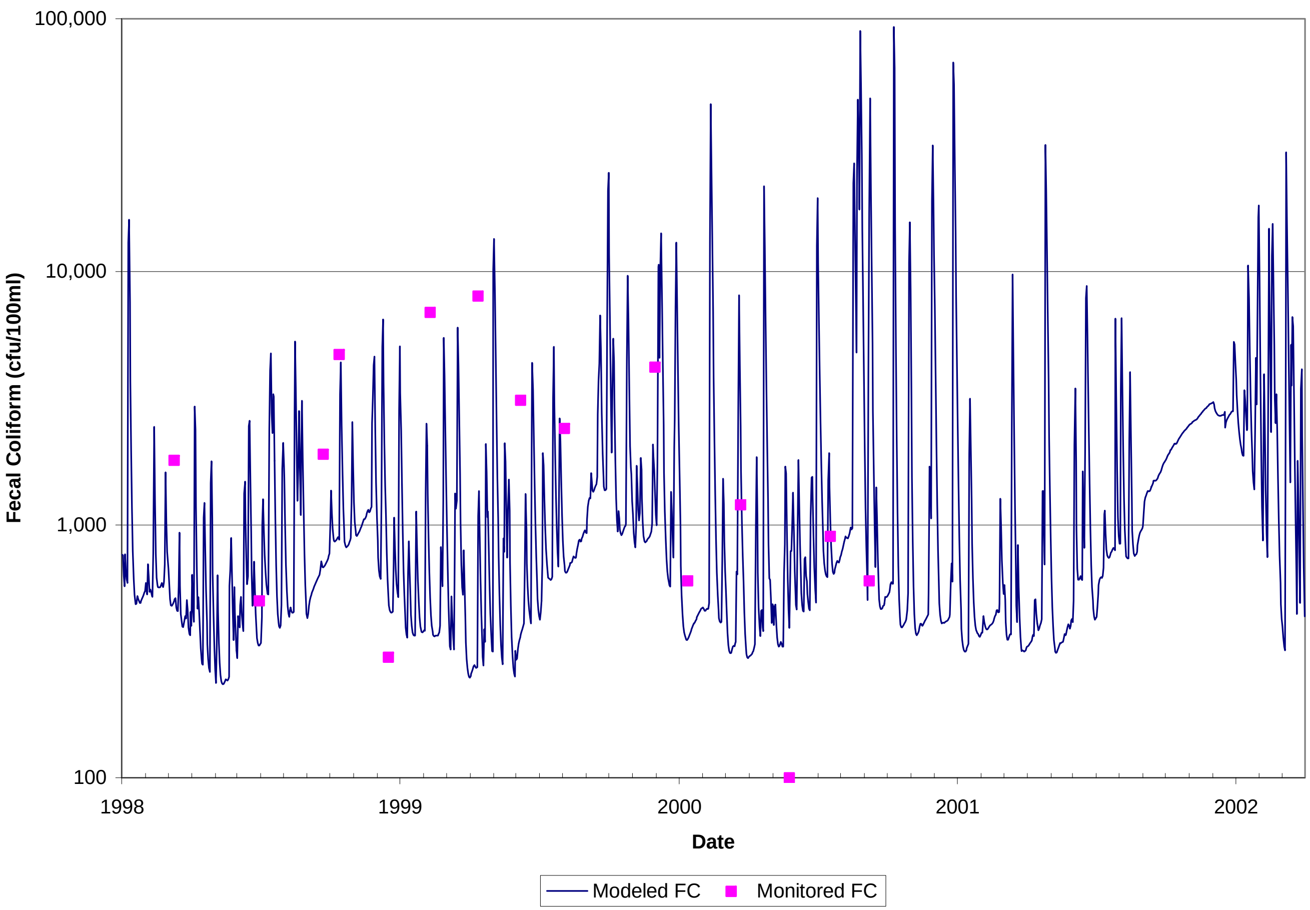


Figure 4.17 **Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 2 in the Back Creek impairment, during the validation period.**

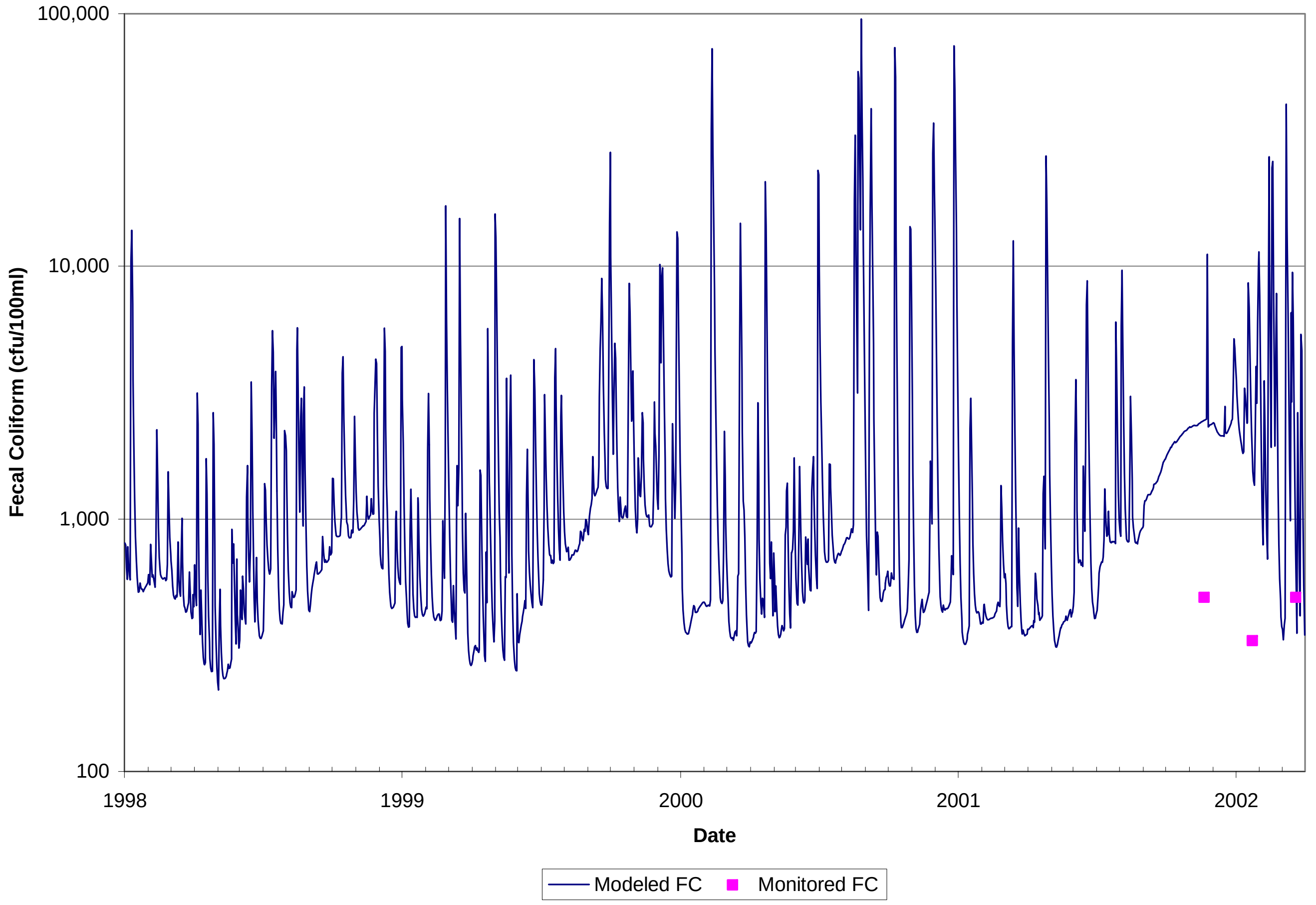


Figure 4.18 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 5 in the Back Creek impairment, during the validation period.

4.8 Existing Loadings

All appropriate inputs were updated to 2003 conditions, as described in Section 4. All model runs were conducted using precipitation data for a representative period used for hydrologic calibration (10/1/86 through 9/30/91). Figure 4.19 shows the monthly geometric mean of *E. coli* concentrations in relation to the 126 cfu/100 ml standard at the outlet of Back Creek. Figure 4.20 shows the instantaneous values of *E. coli* concentrations in relation to the 235 cfu/100 ml standard. Appendix B contains tables with monthly loadings to the different landuse areas in each subwatershed.

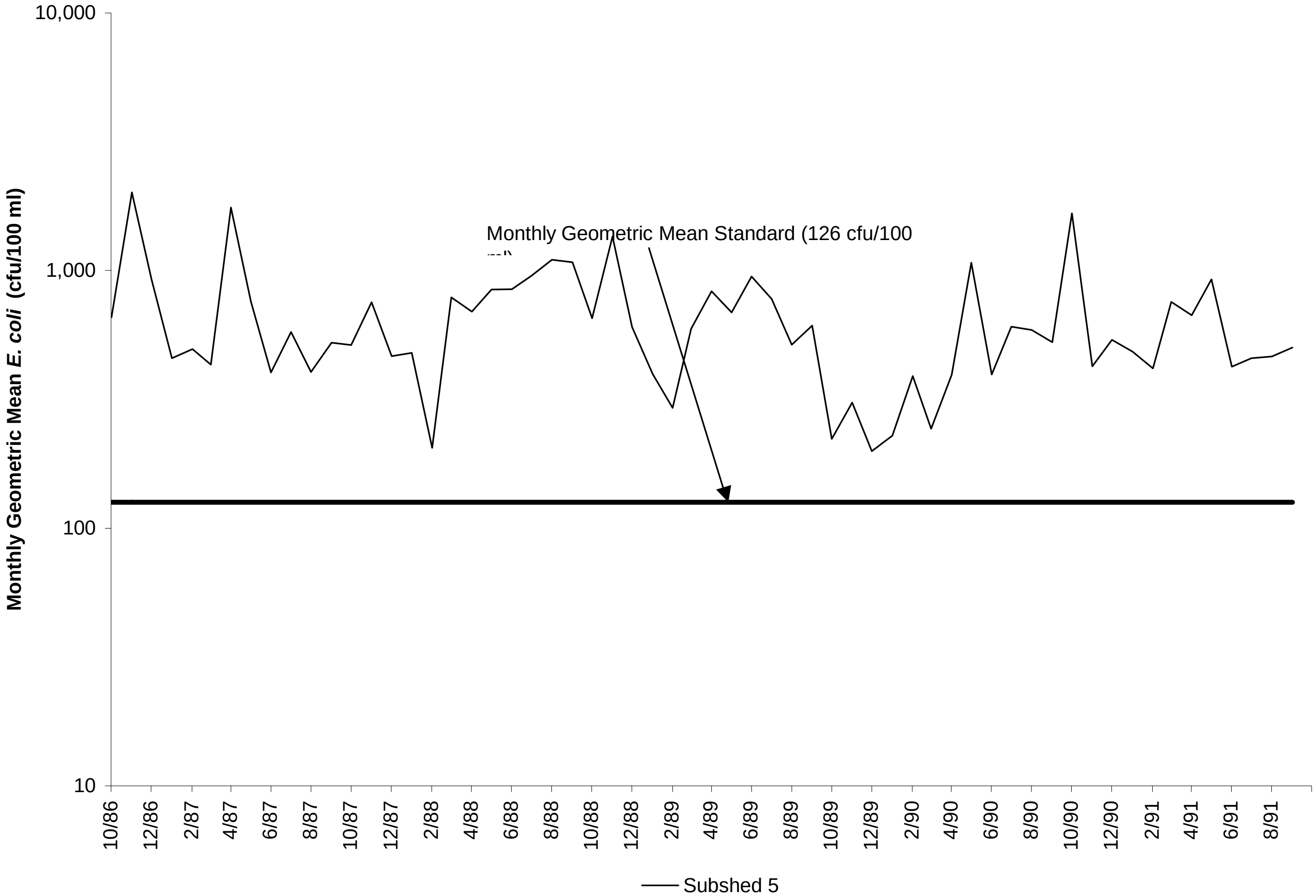


Figure 4.19 Existing conditions (*i.e.*, monthly geometric-mean) of *E. coli* concentrations at the outlet of the Back Creek impairment.

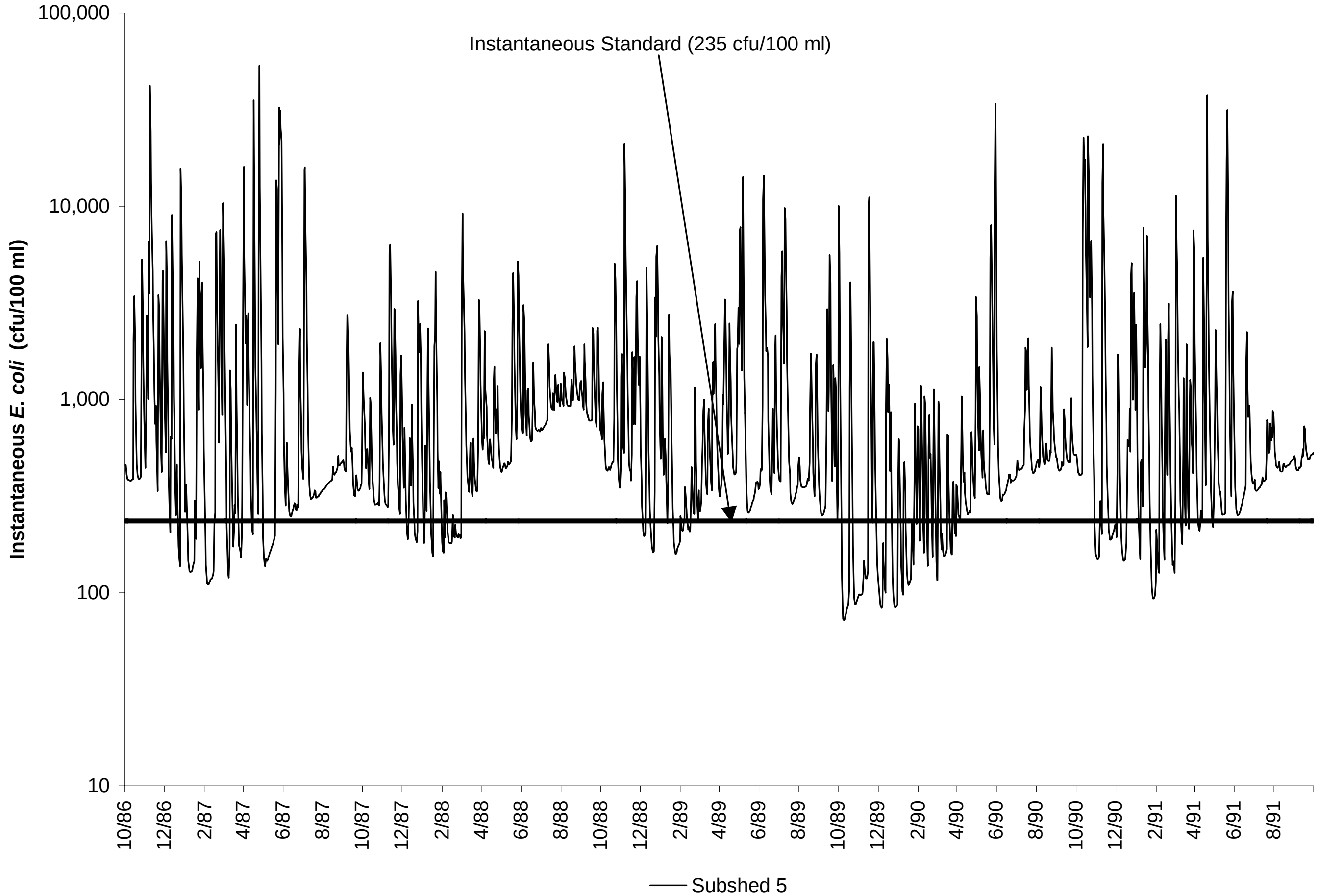


Figure 4.20 Existing conditions (*i.e.*, mean daily) of *E. coli* concentrations at the outlet of the Back Creek impairment.

5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, point sources) and load allocations (LAs, nonpoint sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.*, accuracy of wildlife populations). The definition is typically denoted by the expression:

$$TMDL = WLAs + LAs + MOS$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving water body and still achieve water quality standards. For fecal bacteria, TMDL is expressed in terms of colony forming units (or resulting concentration). A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

5.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, a margin of safety (MOS) was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A margin of safety can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of a MOS in the development of a fecal coliform TMDL is to ensure that the modeled loads do not under-estimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is insured that the recommended reductions will, in fact, succeed in meeting the water quality standard. Examples of implicit MOS used in the development of this TMDL were:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration
- The selection of a modeling period that represented the critical hydrologic conditions in the watershed

- Modeling biosolids applications at the maximum allowable rate and fecal coliform concentration in all permitted fields

5.2 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standards were attained. The TMDL developed for the Back Creek watershed was based on the Virginia State Standard for *E. coli*. As detailed in Section 1.2, the *E. coli* standard states that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml, and that a maximum single sample concentration of *E. coli* not exceed 235 cfu/100 ml. According to the guidelines put forth by the VADEQ (VADEQ, 2003) for modeling *E. coli* with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* through the use of the following equation (developed from a dataset containing n-493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc})$$

Where C_{ec} is the concentration of *E. coli* in cfu/100 ml, and C_{fc} is the concentration of fecal coliform in cfu/100 ml.

Pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the standard was met (Figures 5.7 and 5.8). The development of the allocation scenario was an iterative process that required numerous runs, each followed by an assessment of source reduction against the water quality target.

5.2.1 Wasteload Allocations

There are four point sources currently permitted to discharge in the Back Creek watershed (Figure 3.1 and Table 3.1). Of these sources, only two are permitted for fecal control in the impairment areas. For allocation runs, sources without fecal control permits were modeled as discharging the average recorded value of water, with no *E. coli* bacteria. The allocation for these sources is zero cfu/100 ml. The allocation for the sources permitted for fecal control is equivalent to their current permit levels (*i.e.,* design flow and 126 cfu/100 ml).

5.2.2 Load Allocations

Load allocations to nonpoint sources are divided into land-based loadings from landuses and directly applied loads in the stream (*e.g.,* livestock, sewer overflows, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Within this framework, however, initial criteria that influenced developing load allocations included how sources were linked for representing existing conditions, and results from bacterial source tracking in the area. Land-based NPS loads had the most significant impact during high-flow conditions, while direct deposition NPS had the most significant impact on low flow concentrations. Bacterial source tracking during 2002-2003 sampling periods confirmed the presence of human, pets, livestock and wildlife contamination (Table 5.1).

Allocation scenarios for Back Creek are shown in Table 5.1. Scenario 1 describes a baseline scenario that corresponds to the existing conditions in the watershed. Model results indicate that human, livestock and in-stream depositions by wildlife are significant in all areas of the watershed.

The first objective in running reduction scenarios was to explore the role of anthropogenic sources in standards violations. Scenarios were explored first to determine the feasibility of meeting standards without wildlife reductions. Following this theme, scenario 2 contains 100% reductions in sewer overflows and uncontrolled residential discharges (*i.e.,* straight pipes). Land-based loads were not addressed in this scenario, nor were direct loads from wildlife. This scenario failed to eliminate exceedances.

With scenario 3, attention continued with reductions to anthropogenic sources with 50% reductions to land loads from urban and agricultural lands and a 90% reduction from livestock stream access. As noted in Table 5.1, the number of exceedances is reduced but violations persist. With scenario 4, reduction of land-based loads was increased from 50% to 60% and reduction of livestock stream access was increased from 90% to 100%.

Reductions still do not meet either water quality standard. With land-based reductions increased to 99%, scenario 5 in Table 5.1, the geometric mean standard is met without reductions to wildlife. The instantaneous standard cannot be met without reductions to wildlife. By reducing agriculture NPS loads another 0.3%, the reductions in other loads were reduced. Additional scenarios were made by first exhausting options related to anthropogenic sources, then iteratively making reductions in wildlife until a reduction scenario was found that resulted in zero exceedances of the standard (scenario 8, Table 5.1).

Table 5.1 Allocation scenarios for bacterial concentration with current loading estimates in the Back Creek impairment.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations	
	Direct Wildlife	NPS Wildlife	Direct Livestock	NPS Pasture / Livestock	Res./ Urban	Straight Pipe/ Sewer Overflow	GM > 126 cfu/ 100ml	Single Sample Exceeds 235 cfu/ 100ml
1	0	0	0	0	0	0	100	82.6
2	0	0	0	0	0	100	100	82.6
3	0	0	90	50	50	100	76.7	36.7
4	0	0	100	60	60	100	63.3	31.9
5	0	0	100	99	99	100	0.0	2.74
6	75	75	100	99	99	100	0.0	1.48
7	99	99.5	100	99.5	99.5	100	0.0	0.44
8	38	93	100	99.8	95	100	0.0	0.0

Figures 5.1 and 5.2 show graphically the existing and allocated conditions for the geometric-mean concentrations and instantaneous concentrations in the impairment. Table 5.2 indicates the land-based and direct load reductions resulting from the final allocation. Table 5.3 shows the final TMDL loads for all of the impairments.

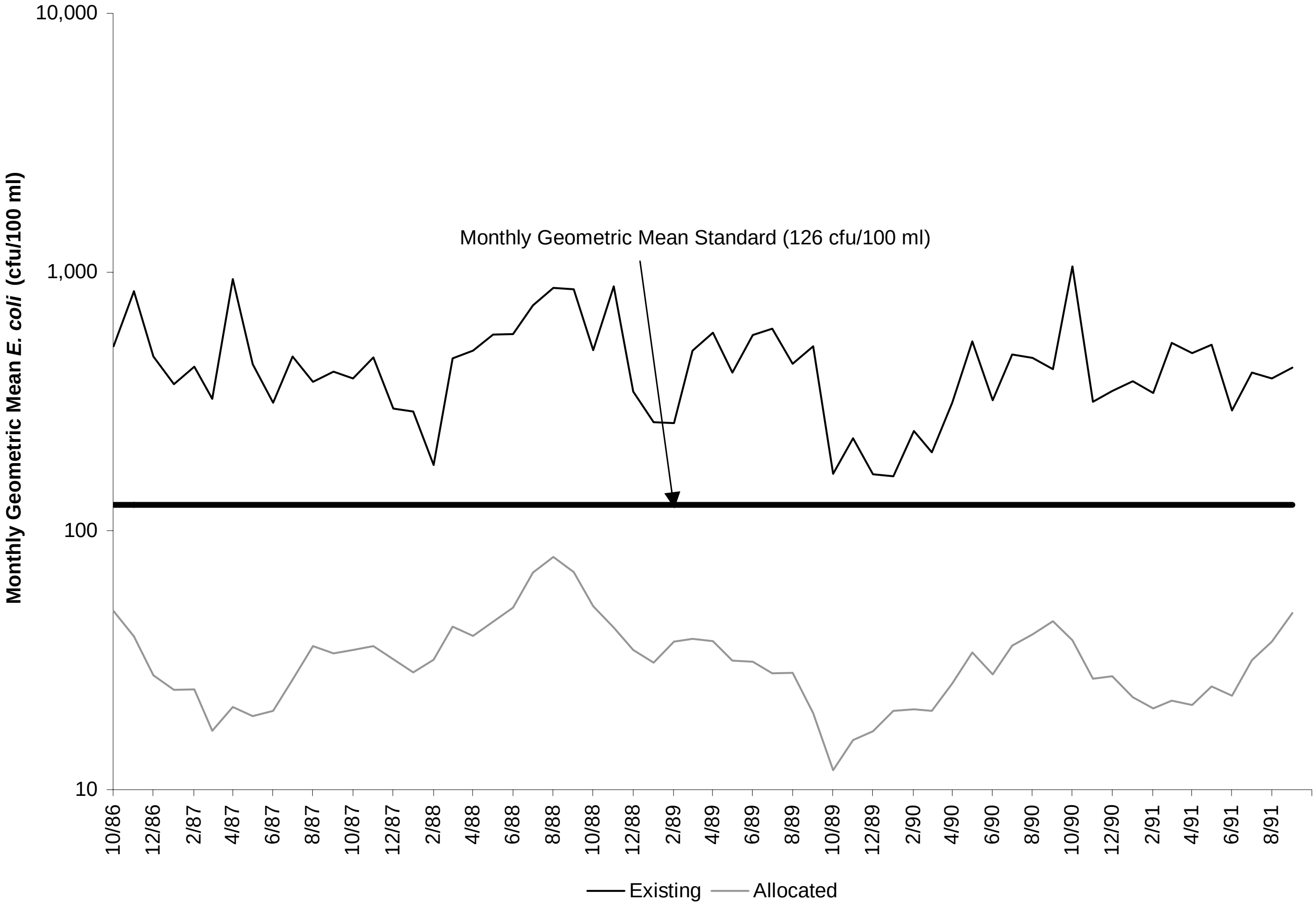


Figure 5.1 The monthly geometric mean standard (*E. coli*) of allocation and existing scenarios for the Back Creek impairment.

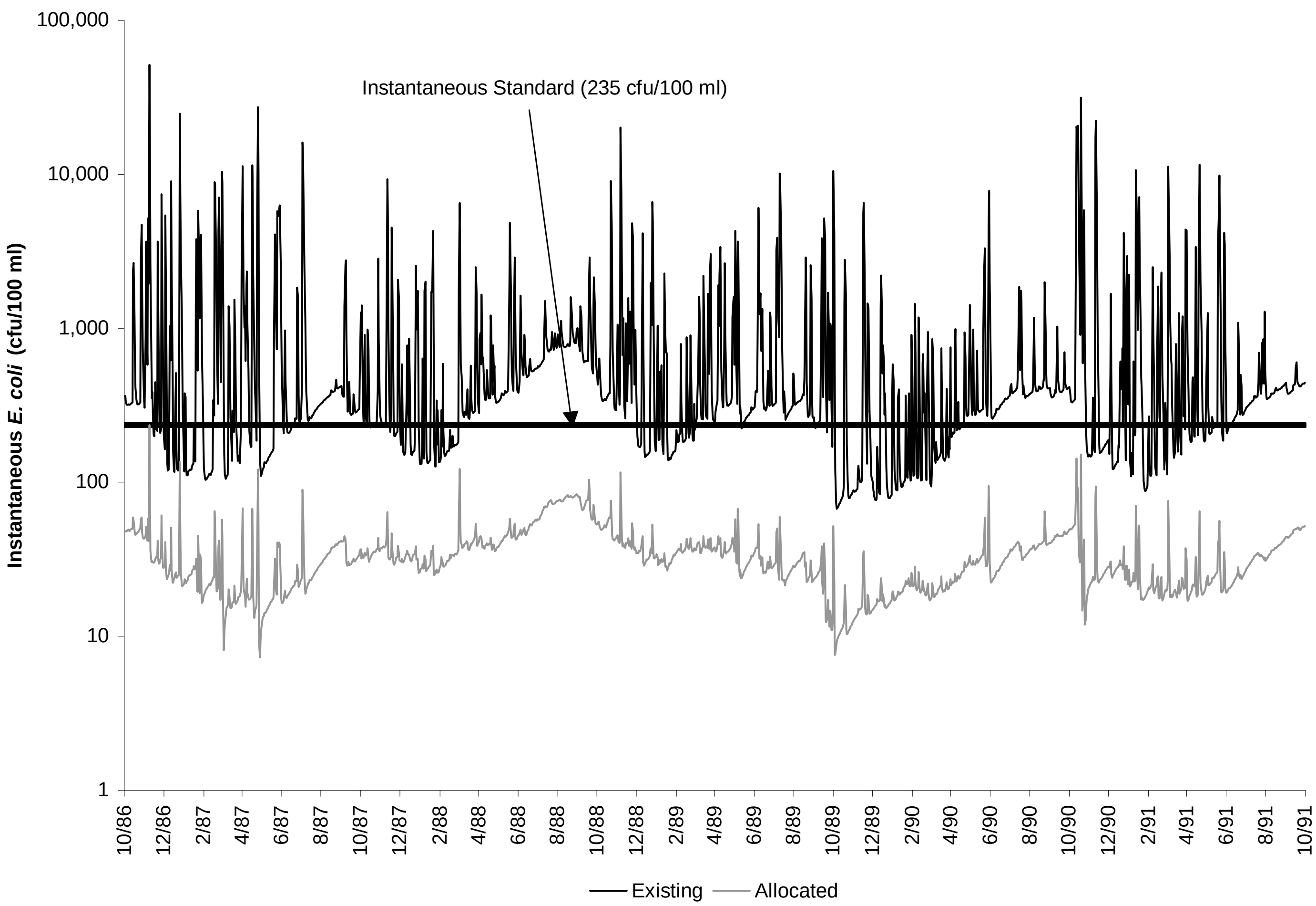


Figure 5.2 The instantaneous *E. coli* concentration of allocation and existing scenarios for the Back Creek impairment

Table 5.2 Land-based and Direct nonpoint source load reductions in the Back Creek impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Residential	7.15E+13	3.58E+12	95
Commercial	1.28E+12	6.40E+10	95
Barren	2.18E+11	4.36E+08	99.8
Cropland	4.51E+15	9.01E+12	99.8
Livestock Access	3.23E+14	6.46E+11	99.8
Pasture	4.34E+15	8.68E+12	99.8
Forest	2.97E+14	2.38E+13	93
Water	0.00E+00	0.00E+00	0
Direct			
Livestock	3.62E+15	0.00E+00	100
Wildlife	1.31E+13	8.12E+12	38
Straight Pipes	1.90E+11	0.00E+00	100

Table 5.3 Average annual *E. coli* loads (cfu/year) modeled after TMDL allocation in the Back Creek watershed impairment.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Back Creek (FC)	2.61E+09	1.02E+13	Implicit	1.02E+13
VAG402033[1]	*8.70E+08*			
VAG402086[1]	*1.74E+09*			

[1] General permits – single family home

To determine if the allocation scenario presented (Table 5.1, scenario 8) will be applicable in the future, the same scenario was evaluated with an increase in permitted loads. The permitted loads were increased by a factor of 5 to simulate a population growth. This future scenario resulted in no violations of the geometric or instantaneous *E. coli* standard. The TMDL table that reflects this future scenario is in Appendix E.

PART III: GENERAL WATER QUALITY (BENTHIC) TMDLS

6. WATER QUALITY ASSESSMENT

6.1 Benthic Assessment

Back Creek was first listed in 1996 as being moderately impaired based on the RBP II assessment method. Table 6.1 shows the RBP II assessment for Back Creek station 9-BCK009.47.

Table 6.1 The RBPII biological assessment for the last 5 years for Back Creek at station 9-BCK009.47.

Year	Spring score	Spring assessment	Fall score	Fall assessment
1999	37.50	Severely Impaired (BPJ)		
2003			47.83	Moderately Imp.
Seasonal 5-yr average	NA			
Seasonal last 2-yrs average	NA			
Final 5-yr average	NA			
Final 2-yr average	NA			

The General Standard is implemented by VADEQ through application of the Rapid Bioassessment Protocol II (RBP II). VADEQ is also using an alternative method, the Stream Condition Index (SCI), for calculating benthic assessment scores. The SCI uses the same eight biometrics as the RBP II, but does not require a reference station, allowing the benthic condition of different streams to be more directly compared. The SCI is also useful for trend analysis for streams in which more than one reference station has been used.

Two benthic assessments were performed on Back Creek and the results are displayed in Table 6.2. The scores from both assessments indicate that the stream is impaired. In Virginia, streams with an SCI of less than 61.3 are classified as impaired. Fall scores are typically higher than spring scores and this, rather than improved conditions in the stream, probably accounts for the small difference in scores.

Table 6.2 Benthic assessments for Back Creek (Station BCK009.47).

Date	SCI	Status
3/29/1999	32.4	Impaired
9/8/2003	40.1	Impaired

Valuable insight into the stressor(s) causing a particular benthic impairment can often be gained by examining individual metric scores and these are displayed in Table 6.3. Both biological assessments show a similar pattern; a taxa richness of about 50, followed by a large drop in score for the next four metrics (EPT, %Ephem, %PT-H, %Scraper), a high score for %Chironomids, poor scores for %2Dom, satisfactory scores for %MFBI. The last metric displayed is the SCI score, obtained by averaging the eight individual metric scores. In Back Creek, the SCI score is low primarily as a result of the small number of individuals belonging to the sensitive invertebrate families found in the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). The only family well-represented from these orders is Hydropsychidae (%PT-H = 0), a family with facultative species that often become abundant in streams subjected to moderate levels of pollution from fine particulates high in organic matter and nutrients (Voshell, 2002).

Table 6.3 Scores for each metric comprising the SCI for Back Creek.

Date	Taxa	EPT	%Ephem	%PT-H	%Scraper	%Chiron	%2Dom	%MFBI	SCI
9/8/03	50.0	36.0	27.0	0.0	18.0	96.0	32.0	67.0	40.1
3/29/99	54.5	27.3	2.5	0.0	3.7	85.4	38.9	61.3	34.2
mean/median	52.3	31.6	14.8	0.0	10.9	90.7	35.4	64.2	37.6

6.2 Habitat Assessment

Benthic impairments have two general causes, input of pollutants to streams and alteration of habitat in either the stream or the watershed. Habitat can be altered directly by channel modification. Habitat can be altered indirectly by changes in the riparian corridor leading to conditions such as streambank destabilization by landuse changes in the watershed such as increasing the area of impervious surfaces. Habitat assessment for Back Creek will include an analysis of habitat scores recorded by VADEQ biologists.

6.2.1 Habitat assessment at biological monitoring stations

Habitat assessments are typically carried out as part of the benthic sampling, the overall habitat score being the sum of nine individual metrics, each metric ranging from 0 to 20. The classification schemes for both the individual habitat metrics and the overall habitat score for a sampling site are shown in Table 6.4.

Table 6.4 Classification of habitat metrics based on score.

Metric Score	Combined Score	Classification
16-20	151-200	Optimal
11-15	101-150	Suboptimal
6-10	51-100	Marginal
0-5	0-50	Poor

The habitat assessments for Back Creek, displayed in Figure 6.1 and 6.2, indicate problems severe enough to cause impaired conditions; riffles are marginal, sedimentation is apparent and riparian vegetation is poor.

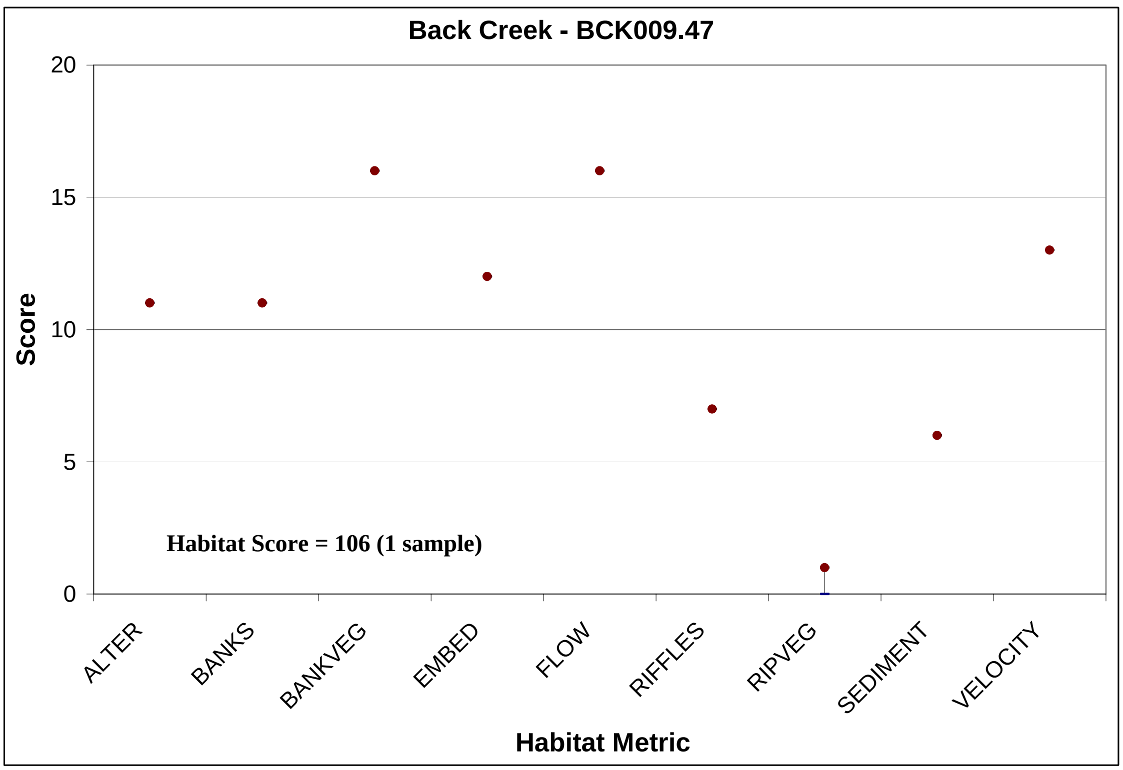


Figure 6.1 Habitat scores for Back Creek at Station 9BCK009.47 during the spring of 1999.

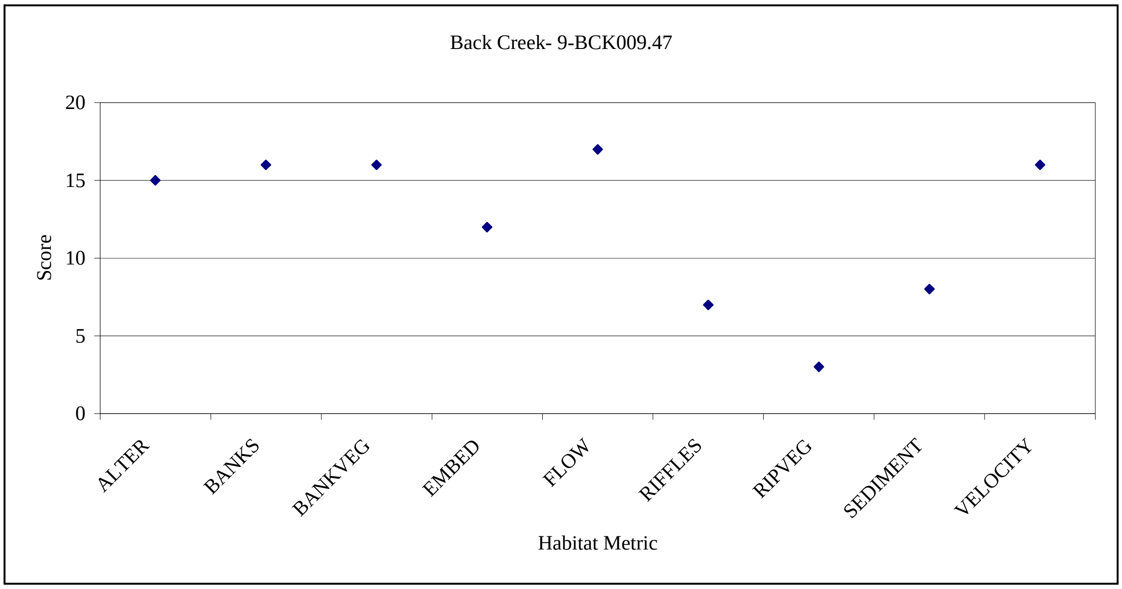


Figure 6.2 Habitat scores for Back Creek at Station 9BCK009.47 during the fall of 2003.

7. TMDL ENDPOINT: STRESSOR IDENTIFICATION AND REFERENCE WATERSHED SELECTION

7.1 Background

Back Creek begins in Pulaski County near Little Walker Mountain in the Jefferson National Forest and flows North-North East before its confluence with the New River near Parrott. It is a third order stream underlain by limestone and dolomite and is influenced by large springs. The dominant landuse is agriculture (pasture and hay). There are two small discharges that fall under VADEQ's general VPDES permit regulation (Table 7.1).

The New River Resource Authority operates a solid waste disposal facility in the watershed, VADEQ permit SWP548. The landfill has been in operation less than five years and VADEQ inspection reports note that there have been no operational problems at the site, (VADEQ personal communication 2/12/2004). There are no known hazardous waste disposal sites in the New River Valley. The VADEQ ambient monitoring stations on Back Creek with recent data are shown in Table 7.2.

Table 7.1 General VPDES Permits in the Back Creek Watershed.

Permit Number	Type	Facility Name	Receiving Stream
VAG402033	Single Family Home	Residence	Back Creek
VAG402086	Single Family Home	Residence	Back Creek

Table 7.2 VADEQ ambient monitoring stations on Back Creek.

Station	Description	Type	Period of Record
9-BCK000.74	Rt. 600 Bridge	Ambient	2002-2003
9-BCK009.47	Rt. 100 Bridge	Ambient	1992-2003
9-BCK015.98	Rt. 363 Bridge	Ambient	2002-2003

Two benthic surveys on Back Creek (3/99) were available for this stressor analysis. The survey site is located at the Rt. 100 Bridge, river mile 9.47. Sinking Creek, a fourth order stream also in the New River Basin, was the reference station used for the Back Creek benthic survey (river mile 12.06 located at the Rt. 42 bridge). Ambient monitoring data from 9-BCK009.47 was used in the analysis because of the length of the data record. Whenever appropriate, data from 9-BCK009.47 is compared with the reference station 9-

SNK012.06. Ambient monitoring data from all the Back Creek stations are included in Appendix D.

TMDLs must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not but they usually do not provide enough information to determine the cause(s) of the impairment. The process outlined in EPA's Stressor Identification Guidance Document (EPA, 2000) was used to separately identify the most probable stressor(s) for Back Creek. A list of candidate causes was developed from published literature and VADEQ staff input. Chemical and physical monitoring data provided evidence to support or eliminate potential stressors. Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). Landuse data as well as a visual assessment of conditions along the stream provided additional information to eliminate or support candidate stressors. The potential stressors are: limited forest cover on first-order streams, sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity, temperature and organic matter.

The results of the stressor analysis for Back Creek are divided into three categories:

> **Non-Stressor**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.
>
> **Possible Stressor**: Those stressors with data indicating possible links, but inconclusive data were considered to be possible stressors.
>
> **Most Probable Stressor**: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

7.1.1 Non-Stressor

7.1.1.1 Temperature

The maximum temperature recorded in Back Creek at Station 9-BCK009.47 was 23.4 ^{o}C, which is well below the specific state standard for the New River Basin of 29 ^{o}C (Figure 7.1). Therefore, temperature was eliminated as a possible stressor.

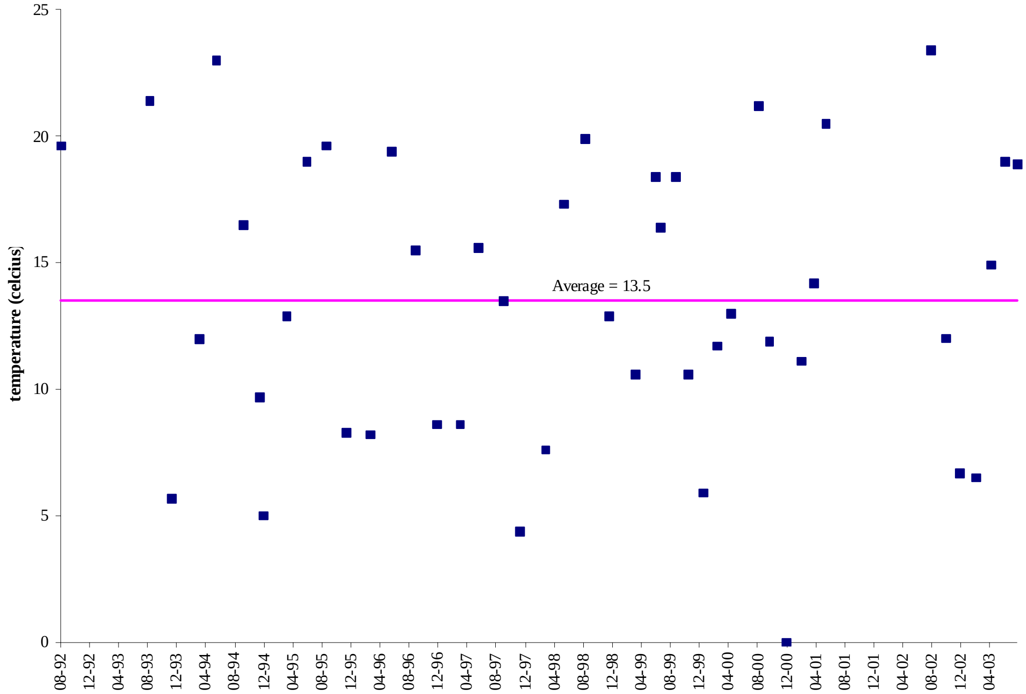


Figure 7.1 Water temperature at Station 9-BCK009.47.

7.1.1.2 pH

The maximum and minimum pH values were within the state standard range of 6 to 9 at the 9-BCK009.47 monitoring station (Figure 7.2). Alkalinity concentrations are also constant and within the expected normal range of 30 - 500 mg/l for this ecoregion (Figure 7.3). Therefore, pH was eliminated as a possible stressor.

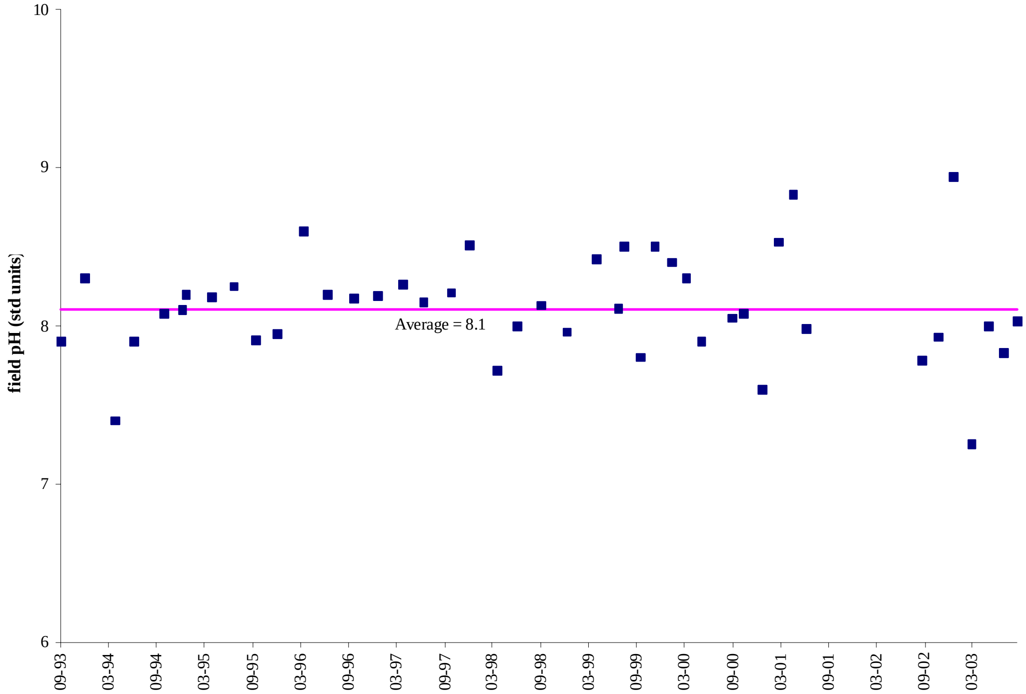


Figure 7.2 Field pH data at Station 9-BCK009.47.

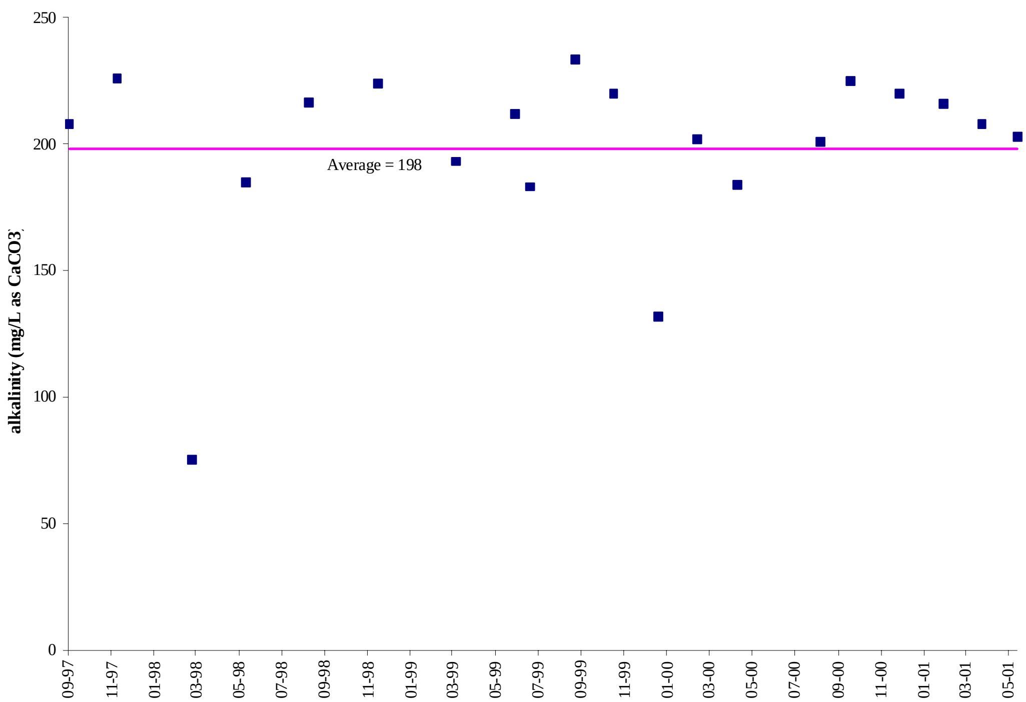


Figure 7.3 Alkalinity concentration at Station 9-BCK009.47.

7.1.1.3 Low Dissolved Oxygen

Dissolved oxygen (DO) concentrations were above the water quality standard at the 9-BCK009.47 monitoring station (Figure 7.4). Large fluctuations in DO concentrations can stress aquatic organisms and is an indication of eutrophication. A diurnal DO study performed by VADEQ found acceptable dissolved oxygen levels with no significant swing in concentrations. Therefore, low DO was eliminated as a possible stressor.

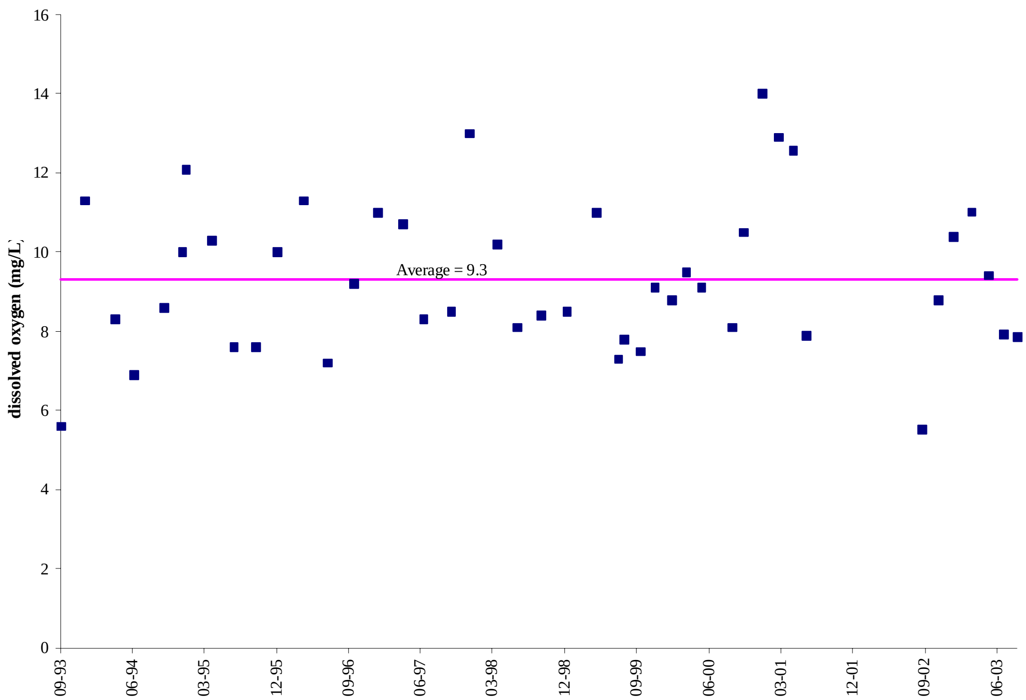


Figure 7.4 Dissolved oxygen concentration at Station 9-BCK009.47.

7.1.1.4 Metals

The water column and sediment monitoring data indicated that metals are not a likely stressor(s) because values were below the appropriate water quality standard or consensus based Probable Effect Concentration (PEC; MacDonald et al., 2000) screening value.

7.1.1.5 Toxics

The water column and sediment monitoring data indicated that toxics are not likely stressors because values were below the appropriate water quality standard or PEC screening value. Median ammonia concentrations were below the typical freshwater background level of 0.1 mg/l (Figure 7.5). There were occasional spikes but, these were below the acute water quality standard. Chloride concentrations were below the EPA chronic water quality criterion of 230 mg/l (Figure 7.6). Fish tissue and sediment sampling were performed at monitoring station 9-BCK009.47 on June 21, 2000. No values exceeded VADEQ water quality standards in fish tissue and sediment values were all well below PEC screening levels.

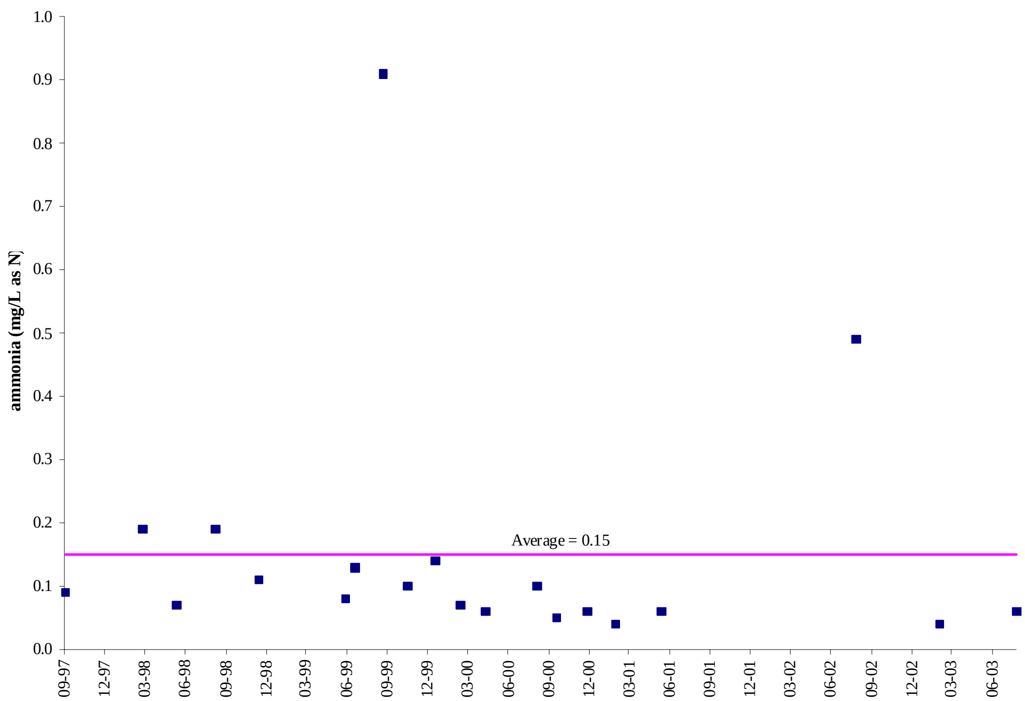


Figure 7.5 Ammonia concentration at Station 9-BCK009.47.

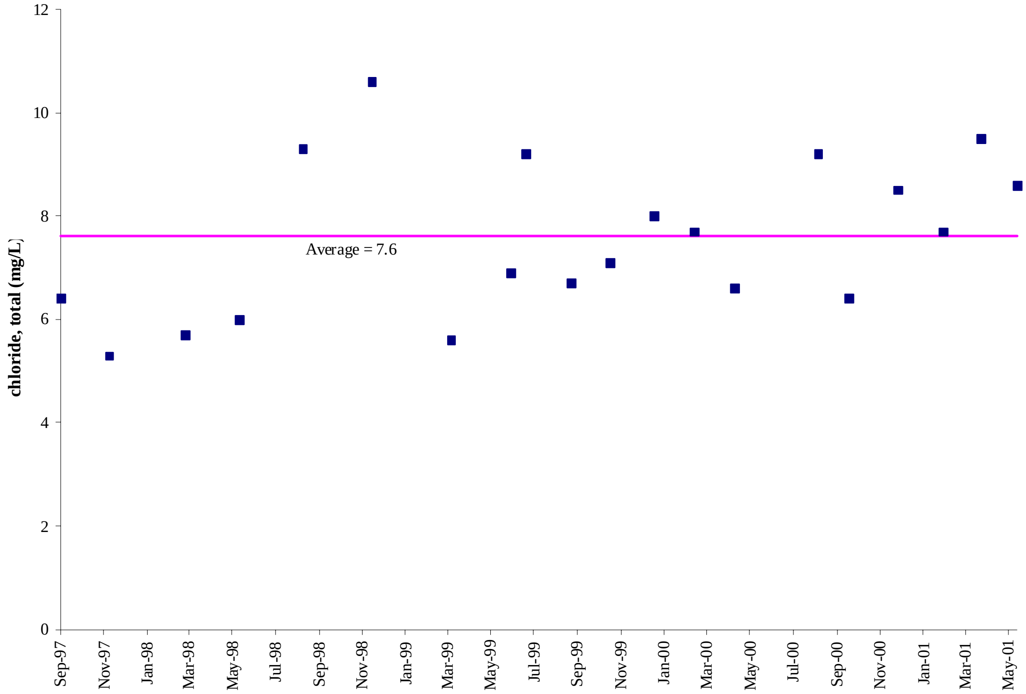


Figure 7.6 Chloride concentration at Station 9-BCK009.47.

7.1.1.6 Conductivity

Extremely high or wide swings in conductivity can cause environmental stress for benthic macroinvertebrates. Conductivity values at 9-BCK009.47 were moderate (Figure 7.7). The average was below 500 µmho/cm, which is reasonable for streams in this ecoregion, (Moeykens, 2002). Conductivity was eliminated as a potential stressor.

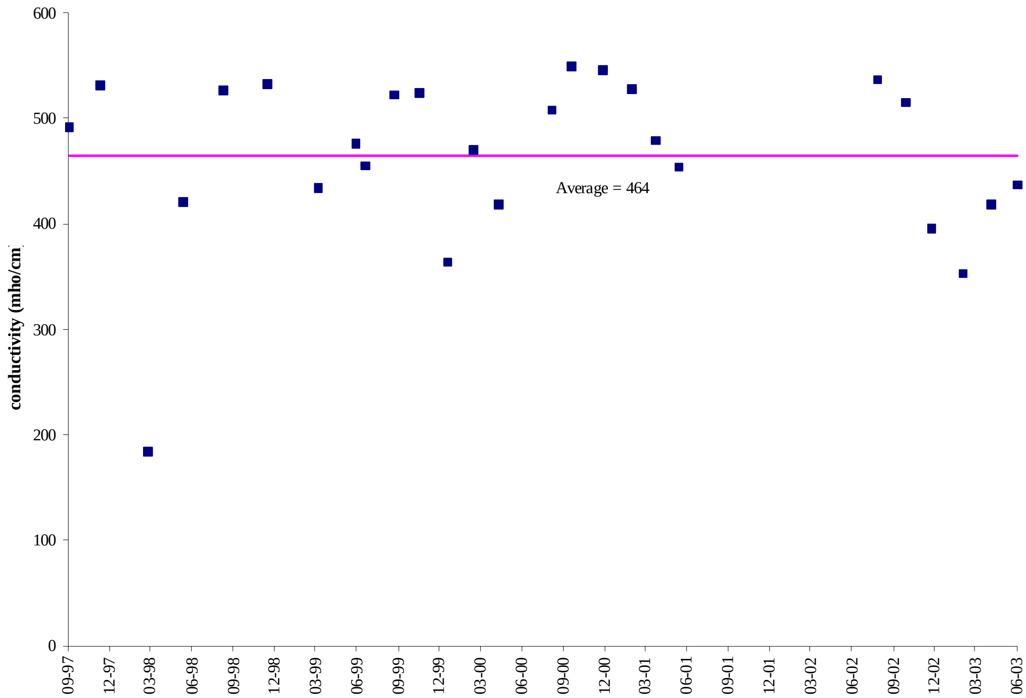


Figure 7.7 Conductivity at Station 9-BCK009.47.

7.1.1.7 Nutrients

Median total phosphorus (TP) concentrations were below the VADEQ assessment screening value of 0.2 mg/l, although there were occasional spikes (Figure 7.8). Median nitrate nitrogen (NO_3-N) values were below an acceptable background level of 1.0 mg/l, however there were spikes up to 2.39 mg/l (Figure 7.9). A thorough examination of nutrients was performed to determine the potential for eutrophication. The criteria used can be found in *Water Quality Assessment: A Screening Procedure For Toxic and Conventional Pollutants* by W.B.Mils, J.D. Dean and D.B. Porcella et al, (1985). The results indicated that TP was the limiting nutrient in the majority of cases. Furthermore, 83% of the TP concentrations were below the Problem Likely to Exist (PLE) threshold. The opposite was true for total nitrogen (TN), where concentrations exceeded the PLE the majority of the time. Minor increases in TP concentrations could have potential to cause eutrophication problems in Back Creek if conditions are favorable. In addition, there was a significant jump in NO_3-N values from June of 2001 to the present. Nutrient concentrations should be monitored closely by VADEQ to determine the source of the NO_3-N and assure that TP concentrations remain low. Wooded riparian buffers remove and assimilate nutrients from the water column, reducing instream nutrient concentrations. In addition, the shade provided inhibits eutrophication. Back Creek's habitat score for Riparian Vegetation was extremely poor (one out of a possible 20). However, data from a diurnal DO study on Back Creek (August 18 to 20, 2003) indicated that nutrients do not threaten the aquatic life in the stream (Figure 7.10). Although there is a well-defined diurnal pattern indicating significant primary production of algal growth, the minimum DO levels remain at nearly 70% of the saturation value and the diurnal swing is not sufficient to stress the benthic community. Nutrients are not considered significant stressors at this time but they have the potential to affect aquatic life in the future.

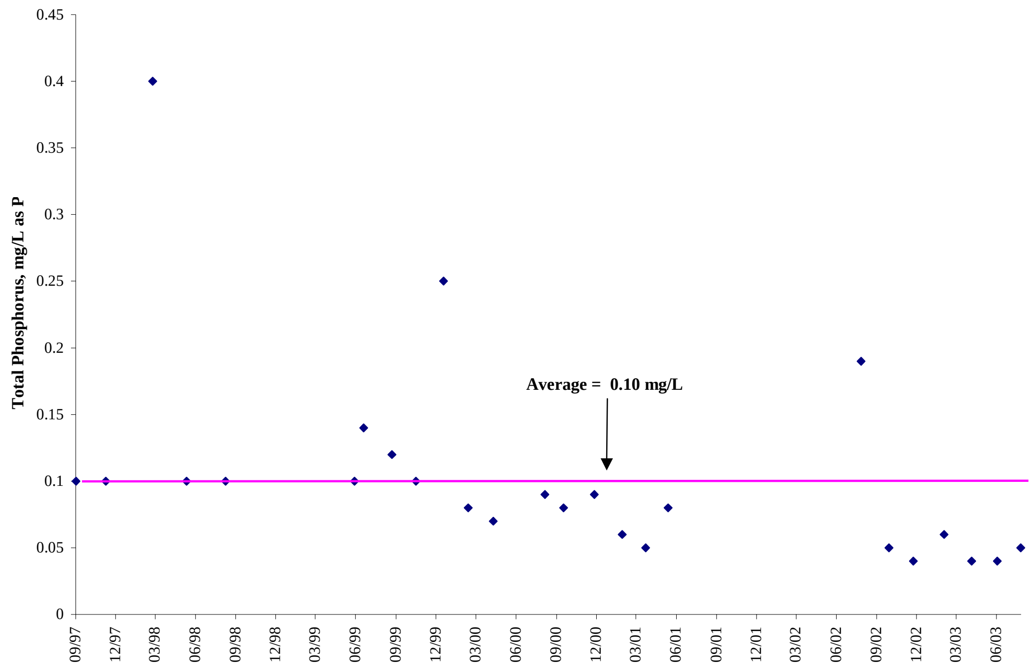


Figure 7.8 Total phosphorus concentrations at Station 9-BCK009.47.

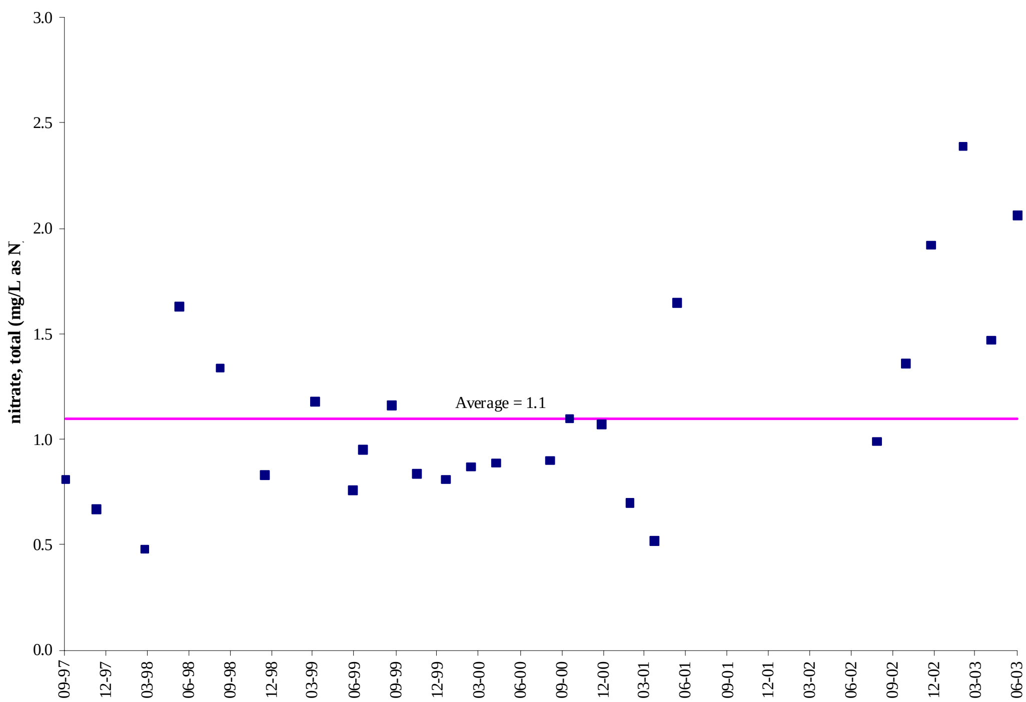


Figure 7.9 Nitrate nitrogen concentrations at 9-BCK009.47.

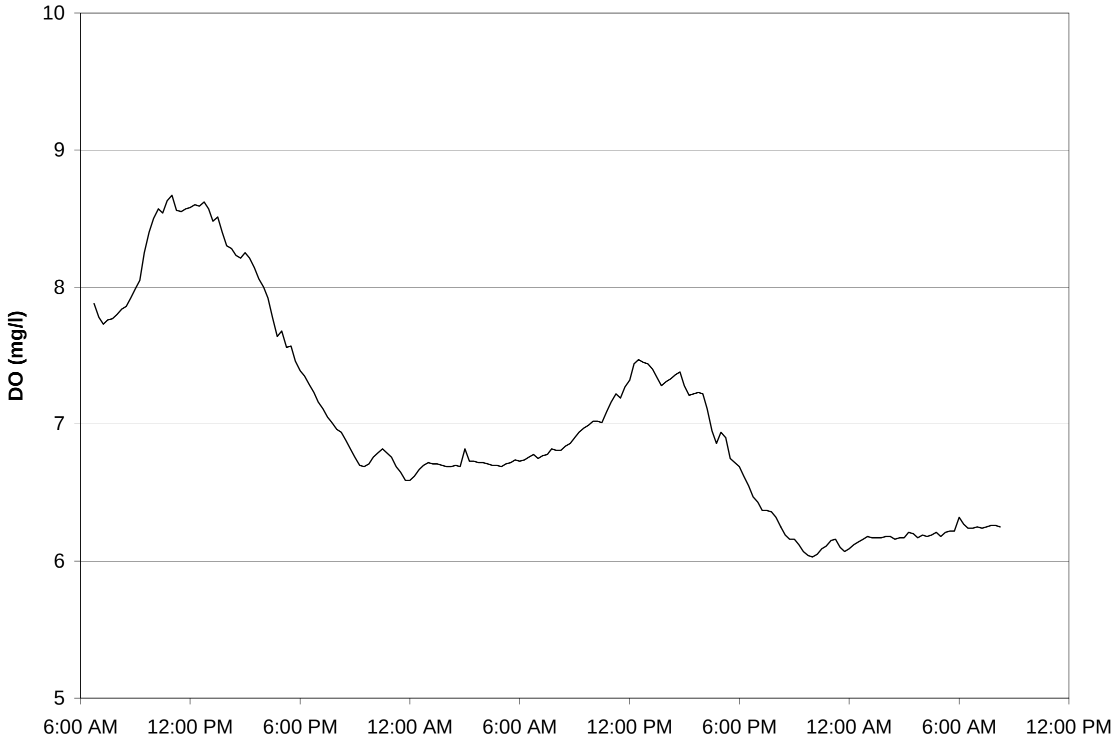


Figure 7.10 Diurnal DO study on Back Creek (8/20/03 – 8/21/03).

7.1.2 Possible Stressors

7.1.2.1 Organic Matter

Several different parameters were used to determine if organic matter levels in the stream impact the benthic macroinvertebrate community. Biochemical oxygen demand (BOD_5) provides an indication of the amount of dissolved organic matter present. Total organic carbon (TOC), chemical oxygen demand (COD), and volatile solids (VS) provide an indication of particulate organic matter in a stream. BOD_5 concentrations were within acceptable levels and there were no extreme values in the data record (Figure 7.11). This suggests that dissolved organic matter is not a significant stressor. COD (Figure 7.12) and TOC (Figure 7.13) were within normal ranges. Volatile solids concentrations were elevated in Back Creek (Figure 7.14). Median VS concentrations in Back Creek were more than double those in Sinking Creek, the reference station (Figure 7.15). The benthic metric MFBI can be an indicator of excessive organic solids. The average MFBI score was significantly higher at the impaired station relative to the reference station

(Sinking Creek SNK012.06). MFBI scores ranged from 0 to 10 and increasing values correlate with increasing organic matter. The score for the 9-BCK009.47 survey was 576. Hydropsychidae and Chironomidae were the dominant families in the benthic survey. They accounted for 73% of the total number of individuals collected. This indicates that there is an excess of fine particulate organic matter. Based on this information, organic matter is a possible stressor.

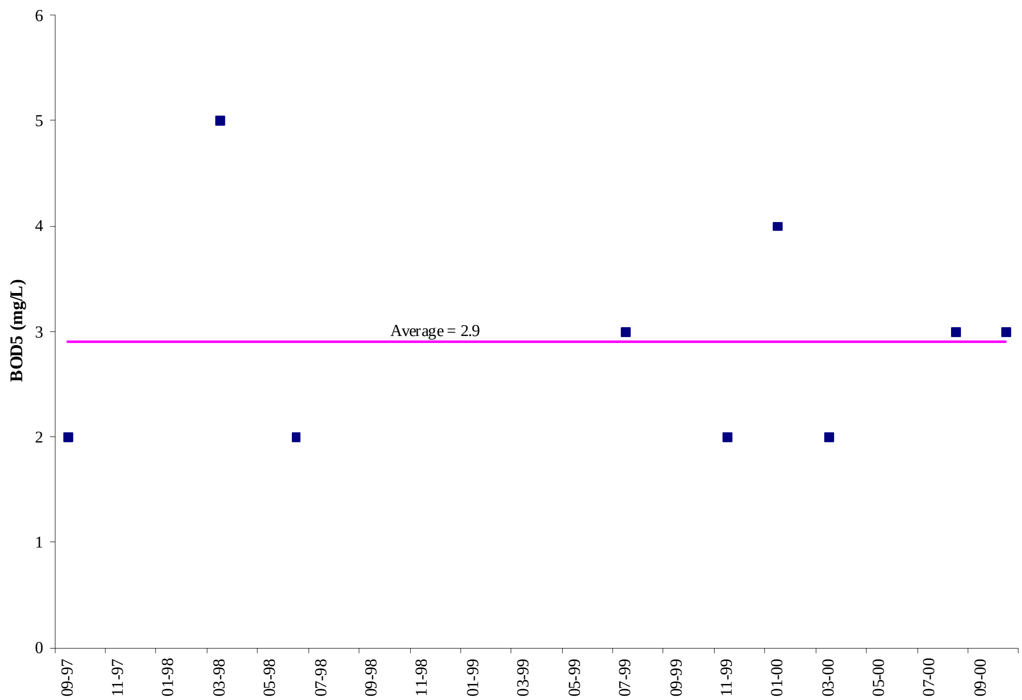


Figure 7.11 BOD_5 concentrations at Station 9-BCK009.47.

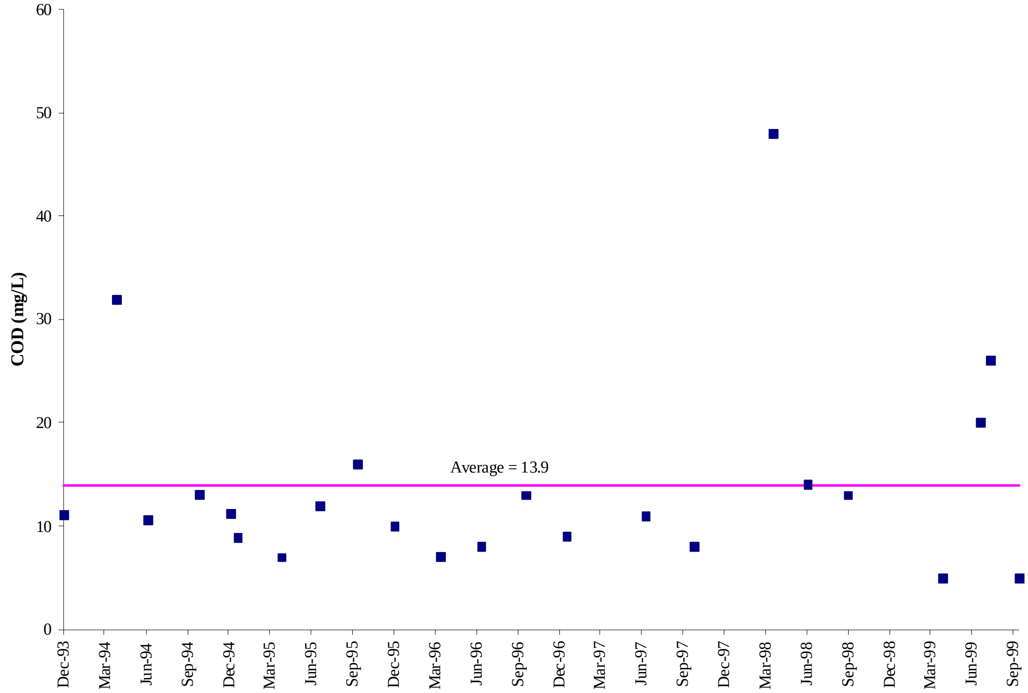


Figure 7.12 COD concentrations at Station 9-BCK009.47.

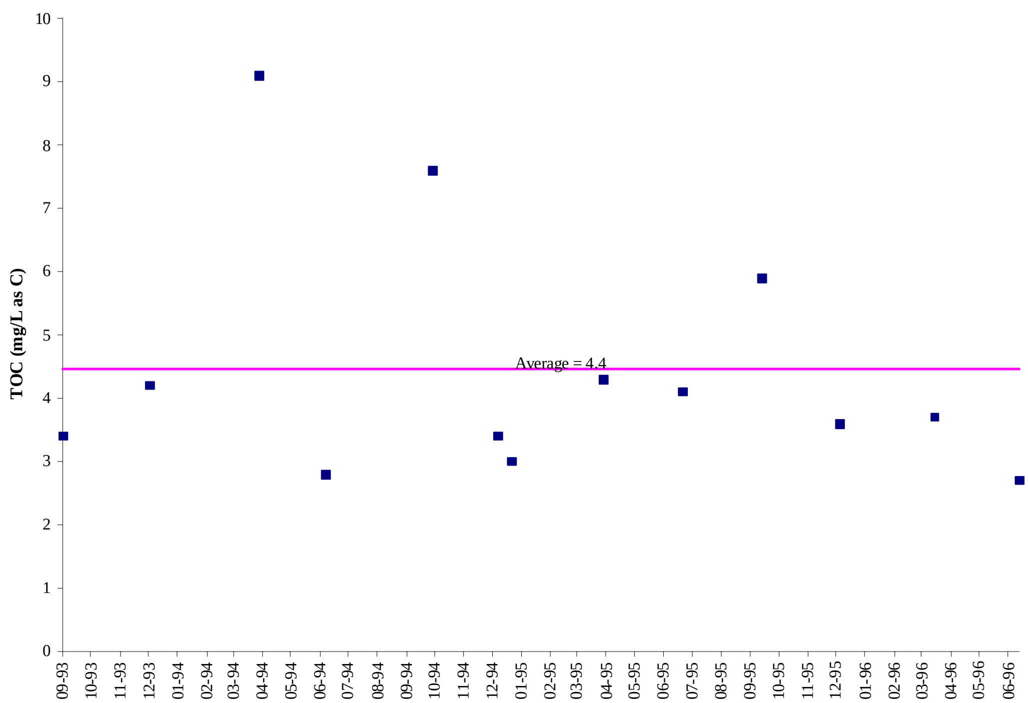


Figure 7.13 TOC concentrations at Station 9-BCK009.47.

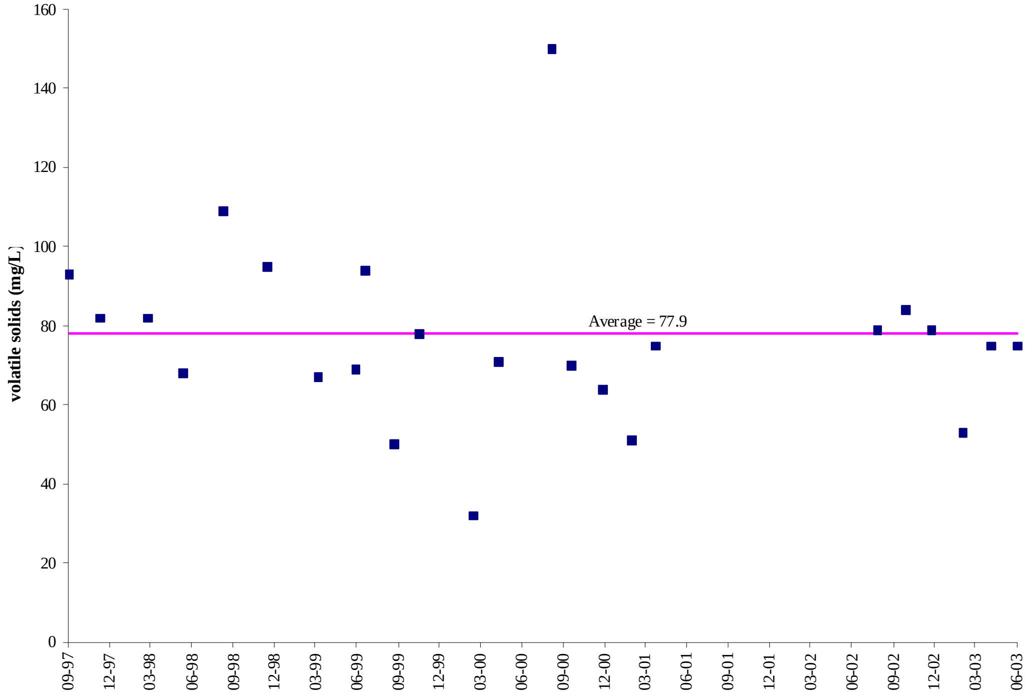


Figure 7.14 Volatile solids concentrations at Station 9-BCK009.47.

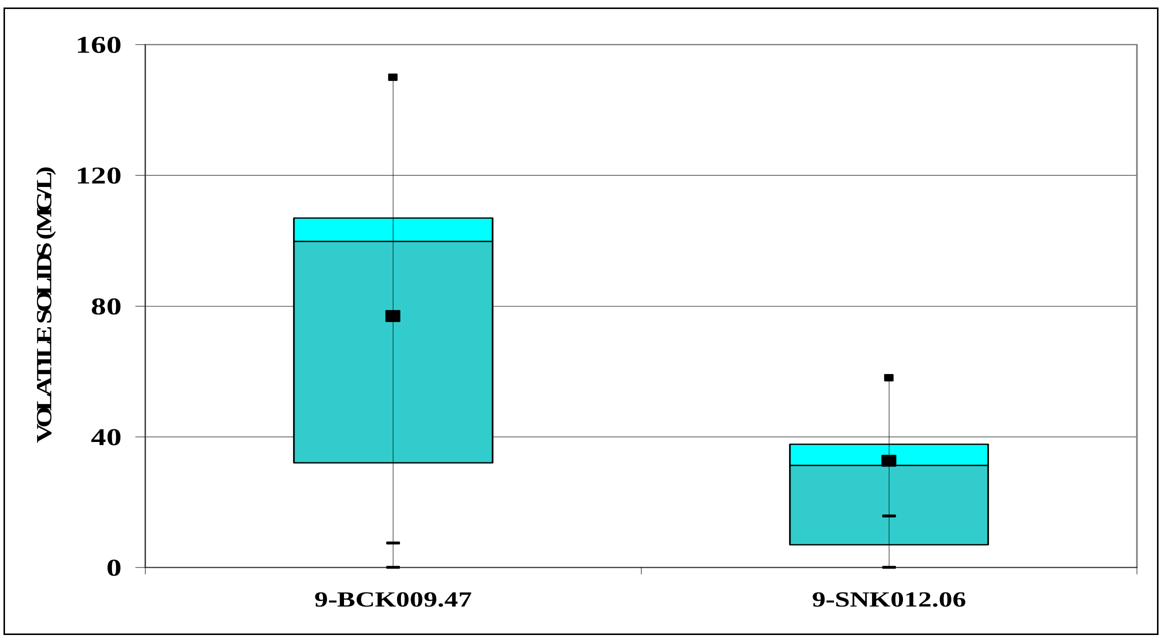


Figure 7.15 Box & whisker plot of volatile solids concentrations at Station 9-BCK009.47.

7.1.3 Most Probable Stressor

7.1.3.1 Sediment

Values for habitat and benthic metrics show that sediment is the most probable stressor. The sediment score on the habitat evaluation indicated moderate deposits of fine sediment in gravel and sand bars and in pool areas. High levels of sediment are indicative of unstable and continually changing environments that are unsuitable for sensitive organisms. The Back Creek benthic survey was dominated by Hydropsychidae, Chironomidae (a), and Simuliidae. These families are moderately pollution tolerant (six on a scale from zero to 10). The EPT Index metric was nearly 75% less than what is normally found in non- impaired streams in this ecoregion. Although this can indicate toxic conditions, it is most likely the result of sediment smothering the sensitive organisms and eliminating their habitat. The embeddedness habitat score was suboptimal (12 out of a possible 20), which indicates that the velocity and stream gradient were not sufficient to keep fine particulate solids from building up in the riffle areas. VADEQ staff at the West Central Regional Office note that Back Creek is nearly always turbid at the Rt.100 Bridge (river mile 9.47). The differences in total suspended solids (TSS) concentrations between the monitoring stations on Back Creek and Sinking Creek (the reference station) are shown in Figure 7.16 (for an unbiased comparison the sampling time frame for the upstream and downstream Back Creek monitoring stations was used). Median TSS concentrations at 9-BCK009.47 are nearly five times higher than those at 9-SNK012.06. There is a considerable difference between station 9-BCK009.47 and the upstream station (9-BCK015.98) and downstream station (9-BCK000.74). Median TSS concentrations were more than double at station 9-BCK009.47. A TSS concentration of 422 mg/l was recorded at 9-BCK009.47 on March 19, 1998. The landuse above the 9-BCK009.47 is agricultural. Livestock have full access to the stream, which has little or no riparian vegetation. This evidence suggests sediment is a probable stressor on the benthic community. Sediment was used as the target pollutant to address the benthic impairment in Back Creek.

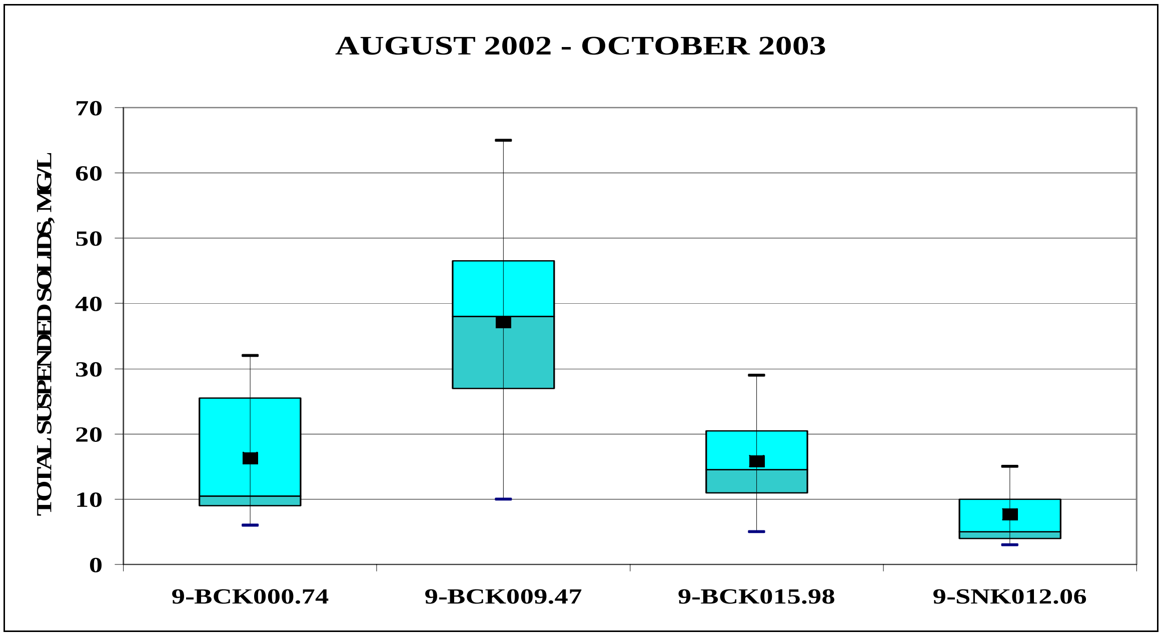


Figure 7.16 Box and whisker plot of TSS concentrations in Back Creek and Sinking Creek.

In summary, sediment was the best and most practical pollutant with which to develop the TMDL due to its interconnection with other possible stressors, *i.e* organic matter and lack of riparian vegetative cover. TP is typically bound to soil particles and enters the aquatic environment by the transport of sediment from the land. For example, reducing livestock access to streams allows streambank vegetation to recover, and reduces inputs of organic matter (manure) as well as nutrients. Stream buffers can reduce overland flow velocities and decrease the amount of sediment and sediment bound nutrients that reach the stream.

7.2 Reference Watershed Selection

A reference watershed approach was used to estimate the necessary load reductions that are needed to restore a healthy aquatic community and allow the streams in the Back Creek watershed to achieve their designated uses. The reference watershed approach is based on selecting a non-impaired watershed that has similar landuse, soils, stream characteristics (*e.g.*, stream order, corridor, slope), and area (not to exceed or be less than double or half the impaired watershed) and is in the same eco-region as the impaired watershed. The modeling process uses load rates in the non-impaired watershed as a target for load reductions in the impaired watershed. The impaired watershed is modeled to determine the current load rates and determine what reductions are necessary to meet the load rates of the non-impaired watershed.

A total of 29 potential reference watersheds were selected from the Central Appalachian Ridges and Valleys eco-region for analysis that would lead to the selection of a reference watershed for Back Creek (Figure 7.17). The potential reference watersheds were ranked based on quantitative and qualitative comparisons of watershed attributes (*e.g.*, landuse, soils, slope, stream order, watershed size, etc.). Based on these comparisons and after conferring with state and regional VADEQ personnel, Toms Creek watershed, Montgomery County was selected as the reference watershed for Back Creek.

Figure 7.18 shows the location of Back Creek and Toms Creek within the eco-region. Figure 7.19 compares the landuse distributions between the two watersheds. Figure 7.20 compares the land slope distributions between the two watersheds, a key parameter in erosion estimates. Figure 7.21 compares runoff potential between the two watersheds as indexed by the soil hydrologic group code. Figure 7.22 compares the soil erosive potential between the two watersheds as indexed by the soil erodibility index. Figure 7.23 compares the available soil moisture storage capacity in the solum between the two watersheds. Finally, Table 7.3 compares drainage characteristics between the two watersheds.

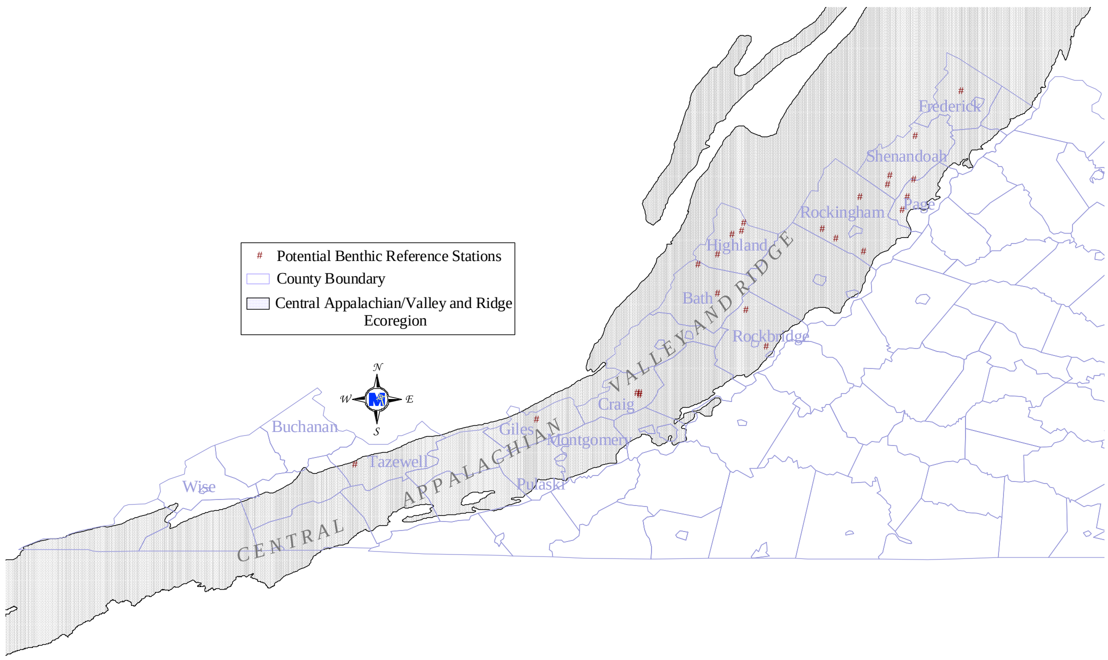


Figure 7.17 Location of potential reference watersheds.

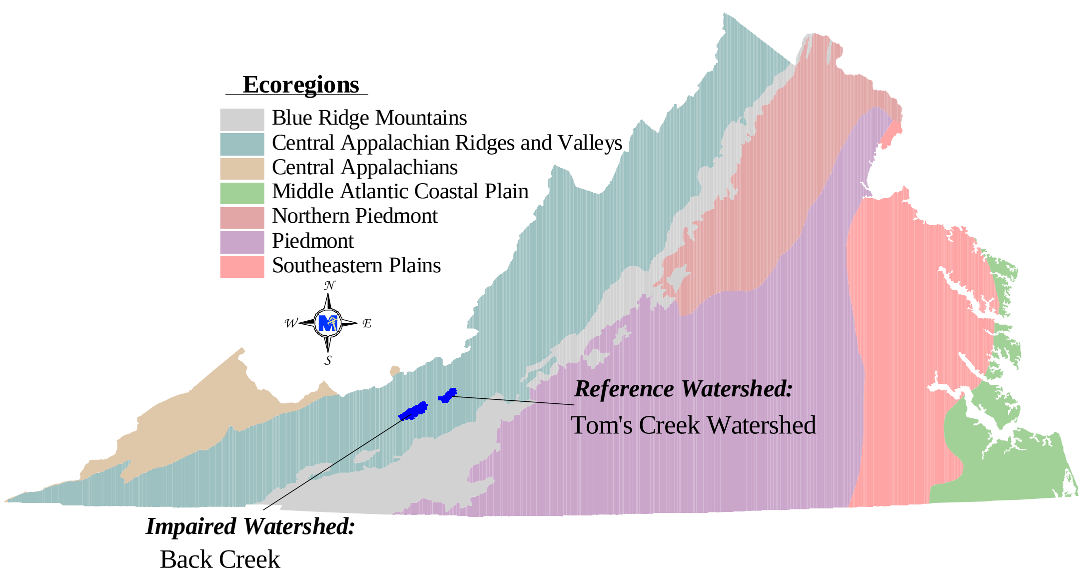
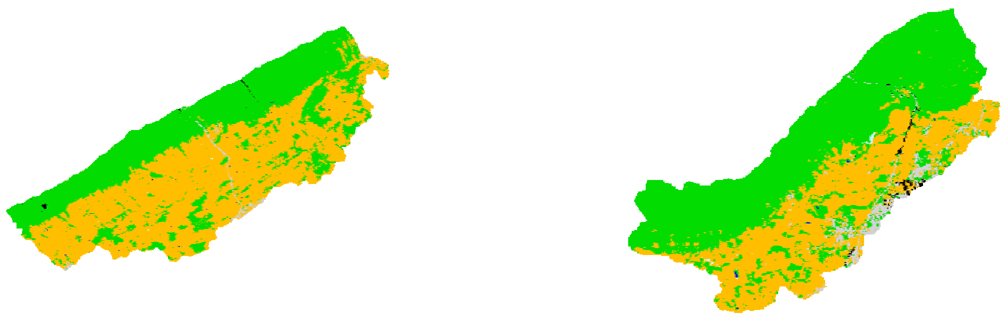


Figure 7.18 Location of impaired and reference watershed within eco-region.

Impaired Watershed **Reference Watershed**



Back Creek Watershed Tom's Creek Watershed

% Landuse in Watershed	Landuse	% Landuse in Watershed
0.67%	Urban	3.50%
42.61%	Forest	58.77%
56.54%	Agriculture	36.98%
0.09%	Transition	0.53%
0.03%	Wetlands	0.15%
0.06%	Water	0.07%

Figure 7.19 Back Creek and Toms Creek landuse comparison.

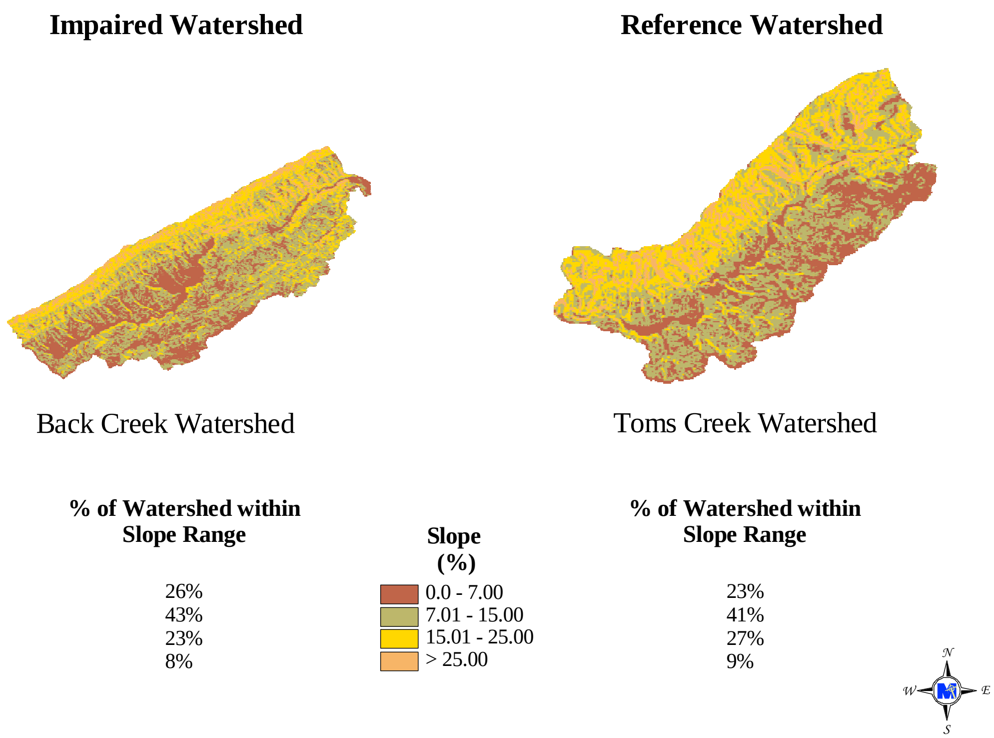


Figure 7.20 Back Creek and Toms Creek slope comparison.

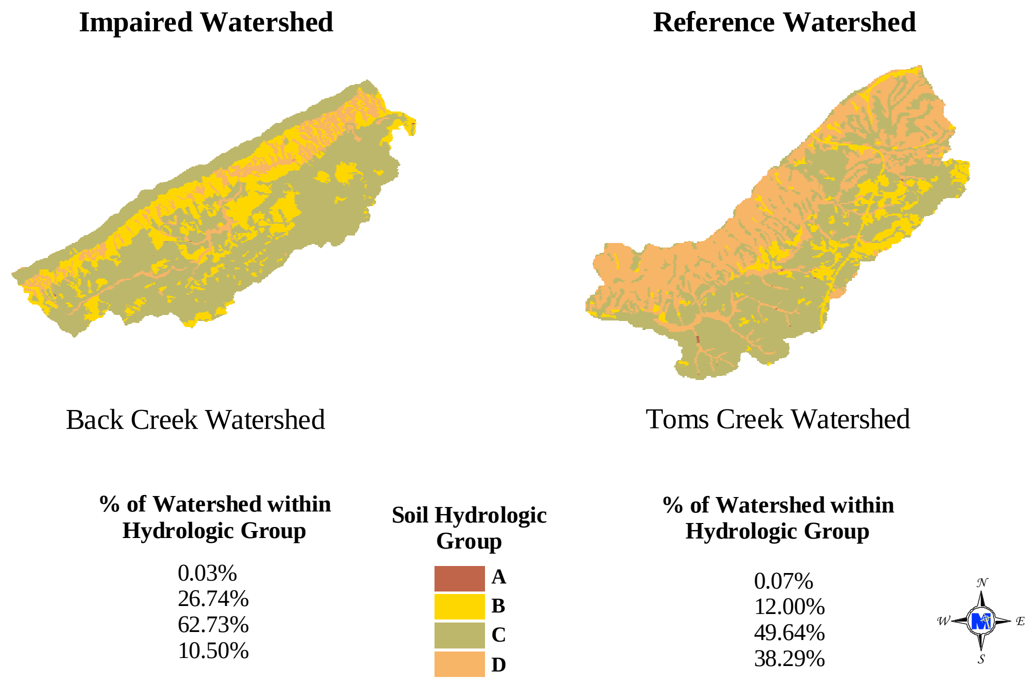


Figure 7.21 Back Creek and Toms Creek soil hydrologic group code comparison.

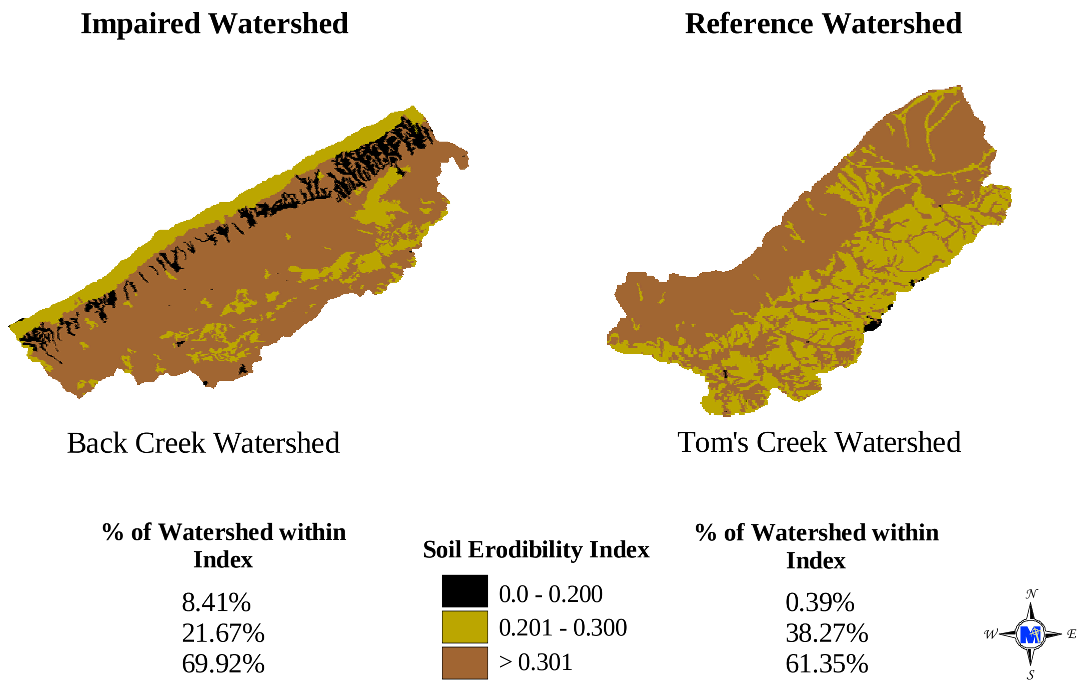


Figure 7.22 Back Creek and Toms Creek soil erodibility index comparison.

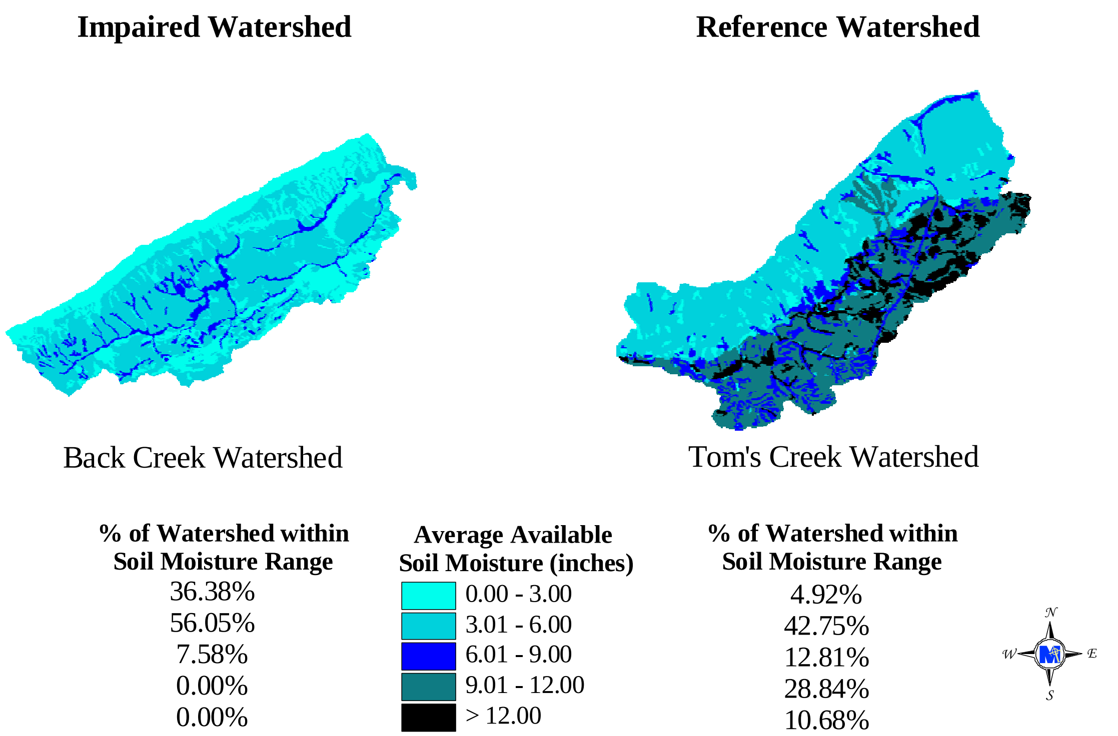


Figure 7.23 Back Creek and Toms Creek soil available moisture storage comparison.

Table 7.3 Back Creek and Toms Creek drainage characteristics comparison.

Watershed	**Stream Length (% Total)**		**Approx. Length-Width Ratio**
	Intermittent	Continuous	
Back Creek	81.0	19.0	3.14
Toms Creek	80.5	19.5	3.10

8. MODELING PROCEDURE

A reference watershed approach was used in this study to develop benthic TMDLs for sediment for the Back Creek watershed. As noted in Section 7.1.3.1, sediment was identified as the primary stressor for the Back Creek watershed. A watershed model was used to simulate sediment loads from potential sources in both the impaired and reference watersheds. The model used in this study was the Visual *Basic™* version of the Generalized Watershed Loading Functions (GWLF) model with modifications for use with ArcView (Evans et al., 2001). The model also included modifications made by Yagow, et al., 2002 and BSE, 2003. Numeric endpoints were based on unit-area loading rates calculated for the respective reference watershed. The TMDLs were then developed for the impaired watershed based on these endpoints and the results from load allocation scenarios.

8.1 Model Framework Selection

The GWLF model was developed at Cornell University (Haith and Shoemaker, 1987; Haith, et al., 1992) for use in ungaged watersheds. It was chosen for this study as the model framework for simulating sediment. GWLF is a continuous simulation, spatially lumped model. It operates on a daily time step for water balance calculations and monthly calculations for sediment and nutrients from a daily water balance. In addition to runoff and sediment, the model simulates dissolved and attached nitrogen and phosphorus loads delivered to streams from watersheds with both point and nonpoint sources of pollution. The model considers flow input from both surface and groundwater. Landuse classes are used as the basic unit for representing variable source areas. The calculation of nutrient loads from septic systems, stream-bank erosion from livestock access, and the inclusion of sediment and nutrient loads from point sources are also supported. Runoff is simulated based on the Soil Conservation Service's Curve Number method (SCS, 1986). Erosion is calculated from a modification of the Universal Soil Loss Equation (Schwab et al., 1983; Wischmeier and Smith, 1978). Sediment estimates use a delivery ratio based on a function of watershed area and erosion estimates from the modified USLE. The sediment transported depends on the transport capacity of runoff.

For execution, GWLF uses three input files for weather, transport, and nutrient loads. The weather file contains daily temperature and precipitation for the period of record. Data are based on a water year typically starting in April and ending in September. The transport file contains input data related to hydrology and sediment transport. The nutrient file contains primarily nutrient values for the various landuses, point sources, and septic system types, but does include urban sediment buildup rates.

8.2 Model Setup

Watershed data needed to run GWLF used in this study were generated using GIS spatial coverage, local weather data, streamflow data, literature values, and other data. Watershed boundaries for the impaired stream segment and the selected reference watershed were delineated from USGS 7.5 minute digital topographic maps using GIS techniques. The impaired watershed was delineated from the downstream extent of the respective segment impairments. The reference watershed outlet was located approximately five kilometers upstream of biological monitoring station 9-TOM0002.19. The outlet is located immediately upstream of the confluence where the drainage becomes third order. For TMDL development, the total area for reference watershed Toms Creek was equated with the area of Back Creek impairment. To accomplish this, the area of landuse categories in reference watershed Toms Creek was proportionately reduced based on the percentage landuse distribution. After adjustment, the distribution of landuse remained the same as pre-adjustment values.

8.3 Source Assessment

Three source areas were identified as the primary contributors to sediment loading in the impaired watershed that are the focus of this study – surface runoff, point sources, and streambank erosion. The sediment process is a continual process but is often accelerated by human activity. An objective of the TMDL process is to minimize the acceleration process. This section describes predominant sediment source areas, model parameters, and input data needed to simulate sediment loads.

8.3.1 Surface Runoff

During runoff events (natural rainfall or irrigation) sediment is transported to streams from pervious land areas (*e.g.,* agricultural fields, lawns, forest, etc.). Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Agricultural management activities such as overgrazing (particularly on steep slopes), high tillage operations, livestock concentrations (*e.g.,* along stream edge, uncontrolled access to streams), forest harvesting, and construction (roads, buildings, etc.) all tend to accelerate erosion at varying degrees. During dry periods, sediment from air or traffic accumulates on impervious areas and is transported to streams during runoff events. The magnitude of sediment loading from this source is affected by other factors (*e.g.,* the level of wind erosion) from which deposition will occur. Street sweeping and/or other street maintenance operations can reduce sediment deposited from vehicular traffic.

8.3.2 Channel and Streambank Erosion

An increase in impervious land without appropriate stormwater control increases runoff volume and peaks and leads to greater channel erosion potential. It has been well documented that livestock with access to streams can significantly alter the physical dimensions of streams through trampling and shearing (Armour et al., 1991; Clary and Webster, 1990; Kaufman and Kruger, 1984). Increasing the bank full width decreases stream depth, increases sediment, and adversely affects aquatic habitat (USDI, 1998). The Back Creek watershed has significant livestock production.

8.3.3 Point Sources TSS Loads

Fine sediments are included in total suspended solids (TSS) loads that are permitted for various facilities with industrial and construction VPDES permits within the Back Creek watershed. There are 2 single-family residences and 1 industrial stormwater discharger permitted within the watershed. One confined animal feedlot (CAFO) was also permitted within the watershed. The CAFO had a no discharge permit. There were no construction stormwater permits or MS4 permits located in the watershed. Sediment loads from industrial and single family homes are included in the waste load allocation (WLA) component of the TMDL, in compliance with 40 CFRξ130.2(h).

8.4 Source Representation – Input Requirements

As described in Section 8.1, the GWLF model was developed to simulate runoff, sediment and nutrients in ungaged watersheds based on landscape conditions such as landuse/landcover, topography, and soils. In essence, the model uses a form of the hydrologic units (HU) concept to estimate runoff and sediment from different pervious areas (HUs) in the watershed (Li, 1972; England, 1970). In the GWLF model, the nonpoint source load calculation for sediment is affected by landuse activity, *e.g.*, farming practices, topographic parameters, soil characteristics, soil cover conditions, stream channel conditions, livestock access, and weather. The model uses landuse categories as the mechanism for defining homogeneity of source areas. This is a variation of the HU concept, where homogeneity in hydrologic response or nonpoint source pollutant response would typically involve the identification of soil landuse topographic conditions that would be expected to give a homogeneous response to a given rainfall input. A number of parameters are included in the model to index the affect of varying soil-topographic conditions by landuse entities. A description of model parameters is given in Section 8.4.1 followed by a description of how parameters and other data were calculated and/or assembled.

8.4.1 Description of Model Input Parameters

The following description of GWLF model input parameters was taken from a TMDL Draft report prepared by BSE, 2003.

Hydrologic Parameters

Watershed Related Parameter Descriptions

- *Unsaturated Soil Moisture Capacity (SMC): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute – available water capacity.*
- *Recession Coefficient (/day): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph.*
- *Seepage Coefficient (/day): The seepage coefficient represents the amount of flow lost to deep seepage.*

Running the model for a 3-month period prior to the chosen period during which loads were calculated initialized the following parameters.

- *Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.*
- *Initial saturated storage (cm): Initial depth of water stored in the saturated zone.*
- *Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.*
- *Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceding the first day in the weather files.*

Month Related Parameter Descriptions

- *Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that stored sediment is flushed from the system at the end of each Apr-Mar cycle. Model output was modified in order to summarize loads on a calendar year basis.*

- *ET CV: Composite evap-transpiration cover coefficient, calculated as an area-weighted average from landuses within each watershed.*

- *Hours per Day: mean number of daylight hours.*

- *Erosion Coefficient: This a regional coefficient used in Richard's equation for calculating daily erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.*

Sediment Parameters

Watershed-Related Parameter Descriptions

- *Sediment Delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as the inverse function of watershed size (Evans et al., 2001).*

LandUse- Related Parameter Descriptions

- *USLE K-factor: The soil erodibility factor was calculated as an area weighted average of all component soil types.*

- *USLE LS-factor: This factor is calculated from slope and slope length.*

- *USLE C-factor: The vegetative cover factor for each landuse was evaluated following GWLF manual guidance and Wischmeier and Smith (1978).*

- *Daily sediment build-up rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.*

Streambank Erosion Parameter Descriptions (Evans, 2002)

- *% Developed Land: Percentage of the watershed with urban-related landuses- defined as all land in MDR, HDR, and COM landuses, as well as the impervious portions of LDR.*

- *Animal density: Calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by watershed area in acres.*
- *Stream length: Calculated as the total stream length of natural stream channel, in meters. Excludes the non-erosive hardened and piped sections of the stream.*
- *Stream length with livestock access: calculated as the total stream length in the watershed where livestock have unrestricted access to streams, resulting in streambank trampling in meters.*

8.4.2 Streamflow and Weather data

No stream flow data existed within or nearby Back Creek that were appropriate for calibrating the GWLF model. Precipitation and temperature data were obtained from a web site created by BSE (2002) to facilitate the use of the GWLF model. Rainfall from a group of nearby stations was Theissen weighted to provide a single record. Access to the database is through the Virginia Hydrologic Units code.

Table 8.1 Weather stations used in GWLF models for Back Creek and Toms Creek.

Watersheds	Weather Stations (station_id, location, Thiessen weights)	Data Type	Data Period
Back Creek	**Station id**: 440766 **Location**: Blacksburg, 3 SE **Thiessen weight:** 1	Daily Precipitation & Temperature	1/1/1994–3/30/2000
Toms Creek	**Station id:** 440766 **Location:** Blacksburg, 3 SE **Thiessen weight:** 1	Daily Precipitation & Temperature	1/1/1994–3/30/2000

8.4.3 Landuse/landcover classes

Landuse classes were used as the basic response unit for performing runoff and erosion calculations and summarizing sediment transport. Landuse coverages were obtained from Multi-Resolution Land Characteristics (MRLC) data (EPA, 1992) for all impaired and reference watersheds. The landuse categories were consolidated from MRLC classifications as given in Table 8.2. Urban landuse categories- low density residential (LDR), high density residential (HDR), and commercial/industrial/transportation/mining

(COM)- were further subdivided into a pervious (PER) and an impervious (IMP) component. The percentage of impervious and pervious area was assigned from data provided in VADCR's online 2002 NPS Assessment Database (VADCR, 2002). The pasture/hay category was subdivided into five sub-categories- hay, overgrazed pasture, unimproved pasture, improved pasture, and stream edge. The percentage of the pasture/hay acreage that was assigned to each category were obtained from Gall, 2004 and VADCR's online 2002 NPS Assessment Database. Cropland was also sub-divided into two sub-categories- low tillage and high tillage. The percentage assigned to each cropland sub-category was obtained from VADCR's online database (VADCR, 2002) and Gall, 2004. Landuse distributions for Back Creek and Toms Creek are given in Table 8.3. Landuse acreage for Toms Creek was adjusted up by the ratio of impaired watershed to reference watershed maintaining the original landuse distribution.

The weighted C-factor for each landuse category was estimated following guidelines given in Wischmeier and Smith, 1978, GWLF User's Manual (Haith et al., 1992), and Kleene, 1995. Where multiple landuse classifications were included in the final TMDL classification, *e.g.*, pasture/hay, each classification was assigned a C-factor and an area weighted C-factor calculated.

8.4.4 Sediment Parameters

Sediment parameters include USLE parameters K, LS, C, and P, sediment delivery ratio, and a buildup and loss functions for impervious surfaces. The product of the USLE parameters, KLSCP, is entered as input to GWLF. The K factor relates to a soil's inherent erodibility and affects the amount of soil erosion from a given field. Soils data for the Back Creek watershed was obtained from VADCR's VirGIS database for Pulaski County, Virginia (VADCR, 1992) and the Pulaski County soil survey manual (SCS, 1985b). The area-weighted K-factor by landuse category was calculated using GIS procedures. Land slope was calculated from USGS Digital Elevation Models (DEMs) using GIS techniques. The length-of-slope was based on VirGIS procedures given in VirGIS Interim Reports (*e.g.*, Shanholtz et al., 1988). The VirGIS length-of-slope values were developed in cooperation with local SCS Office personnel for much of Virginia. The area-weighted slope and length-of-slope were calculated by landuse category using

GIS procedures. The area-weighted LS factor was calculated for each landuse category using procedures recommended by Wischmeier and Smith (1978). The average soil solum thickness and corresponding available soil moisture capacity were obtained from soils data and used to estimate the unsaturated soil moisture capacity. Soils data for the Toms Creek reference watershed was obtained from the Soil Survey Geographic (SSURGO) database for Virginia (SCS, 2004), Montgomery County and the Montgomery County soil survey report (SCS, 1985b). The area-weighted USLE parameters, K and LS, for Toms Creek were calculated following the procedures outlined for the Back Creek impairment.

8.4.5 Pervious and Impervious Surfaces

Four TMDL categories define urban landuse/landcover (Table 8.3). Each urban area was sub-divided into pervious areas (USLE sediment algorithm applies) and impervious areas where an exponential buildup-washoff algorithm applies. The percentage of pervious and impervious area was calculated from data obtained from VADCR's 2002 NPS Assessment Landuse/Landcover Database (VADCR, 2002).

Table 8.2 Landuse-Categories for TMDL Analysis.

TMDL Landuse Categories	MRLC Landuse Categories
Low Density Residential	Low Density Residential (21)
High Density Residential	High Density Residential (22)
Commercial	Commercial (23)
	Industrial (23)
	Transportation (23)
Transitional	Barren - transitional (33)
	Barren/Bare Rock (31)
	Barren Gravel Pits (32)
Forest	Deciduous Forest (41)
	Evergreen Forest (42)
	Upland - Mixed Forest (43)
	Woody Wetlands (91)
	Shrubland (51)
Urban Grass	Urban Grass (85)
Pasture/Hay	Pasture/Hay (81)
	Grasslands (71)
	Pasture/Hay (81)
	Herbaceous Wetlands(92)
	Orchards/vineyards (61)
Cropland	Row Crops (82)
	Small grain (83)
	Cultivated Fallow (84)
Water	Water (5)

Table 8.3 Landuse distributions for Back Creek and reference watershed Toms Creek.

Landuse Category	Back Creek (ha)	Toms Creek (Adjusted) (ha)
Low Density Residential (LDR-PER)	12.562	173.146
High density Residential (HDR-PER)	0	0.414
Commercial (COM-PER)	19.732	30.657
Transitional	9.54	54.350
Forest		
Forest-FOR	4,267.10	5,890.280
Disturbed-FOR	131.97	182.174
Urban Grass	0.0	0.000
Pasture/Hay		
Hay	476.860	297.545
Overgrazed	466.262	622.576
Unimproved	1,631.916	622.576
Improved	2,564.440	1,867.729
Stream Edge	158.953	25.425
Cropland		
High Tillage	108.453	118.139
Low Tillage	433.811	275.658
Low Density Residential (impervious)	3.752	106.122
High density Residential (impervious)	0.000	0.339
Commercial (impervious)	33.598	50.020
Water	5.724	7.522

Daily sediment build-up rate on impervious surfaces, which represents the daily amount of dry deposition from the air on days without rainfall, was assigned using GWLF manual (Haith et al. 1992) guidance. For this study, the values used by BSE, 2003 were assigned as the daily build up rate.

8.4.6 Sediment Delivery Ratio

The sediment delivery ratio specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size. The sediment delivery ratios for impaired and reference watersheds were calculated as an inverse function of watershed size (Evans et al., 2001).

8.4.7 SCS Runoff Curve Number

The runoff curve number is a function of soil type, antecedent moisture conditions, and cover and management practices. The runoff potential of a specific soil type is indexed by the Soil Hydrologic Group (HG) code. Each soil-mapping unit is assigned HG codes that range in increasing runoff potential from A to D. The soil HG code was given a numerical value of 1 to 4 to index HG codes A to D, respectively. An area-weighted average HG code was calculated for each landuse/land cover from soil survey data using GIS techniques. Runoff curve numbers (CN) for soil HG codes A to D were assigned to each landuse/land cover condition for antecedent moisture condition II following GWLF guidance documents and SCS, 1986 recommended procedures. The runoff CN for each landuse/land cover condition then were adjusted based on the numerical area-weighted soil HG codes.

8.4.8 Parameters for Channel and Streambank Erosion

Parameters for streambank erosion include animal density, total length of streams with livestock access, total length of natural stream channel, percent of developed land, mean stream depth, and watershed area. The animal density was calculated by dividing the number of livestock (beef and dairy) by watershed area in acres. The number of animal units (1000 pound per animal) was obtained from Soil and Water Conservation District personnel. The total length of the natural stream channel was estimated from USGS NHD hydrography coverage using GIS techniques. The length of hardened channel was estimated as equal to the distance of streams flowing through urban areas. The mean stream depth was estimated as a function of watershed area.

8.4.9 Evapo-transpiration Cover Coefficients

Evapotranspiration (ET) cover coefficients were entered by month. Monthly ET cover coefficients were assigned each landuse/land cover condition (from MRLC classification) following procedures outlined in Novotny and Chesters (1981) and GWLF guidance. Area-weighted ET cover coefficients were then calculated for each sediment source class.

8.5 Point Source TSS Loads

Four point sources were identified in the Back Creek watershed with locations shown in Figure 3.1 and discharge specifics listed in Table 8.4. Permitted loads were calculated as the average annual modeled runoff times the area governed by the permit times a maximum TSS concentration of 100 mg/l. The modeled runoff for industrial stormwater dischargers was calculated for both pervious and impervious commercial sediment source areas. The calculations involved calculating a weighted maximum runoff value for commercial areas by multiplying the maximum annual modeled runoff depth from pervious commercial times the percentage of commercial area that is pervious and adding to the maximum annual modeled runoff depth from commercial impervious areas multiplied times the percentage of impervious commercial areas. The weighted maximum runoff (cm) from commercial areas is multiplied by the permit area (ha) times permitted concentration (TSS/mg/L) times 0.00010001 to get permit load in T/yr. A confined animal feedlot permit (CAFO) is a no discharge permit. There were no MS4 permits in the Back Creek watershed.

Table 8.4 Point Sources in the Back Creek watershed.

Back Creek Point Sources		Existing Conditions					Future Conditions
VPDES ID	**Name**	**Permit Discharge (MGD)**	**Runoff (cm)**	**Area (ha)**	**Conc. (mg/L)**	**TSS (T/yr)**	**TSS (T/yr)**
Industrial Stormwater Permits							
VAR050140	Goochs Recycling	-	59.78	0.40469	100	0.246	0.242
Confined Animal Feedlot Permits		-		-	-	0	0.000
VPG120009	Back Creek Dairy						
Single Family Home Wastewater Permits							
VAG402033	Residence	0.00450		-	30		0.019
VAG402086	Residence	0.00450		-	30		0.019
Point Source Totals							**0.280**

8.6 Stream Characteristics

The GWLF model does not support in stream flow routing. An empirical relationship developed by Evans et al., 2001 and modified by BSE, 2003 requires total watershed stream length of the natural channel and the average mean depth for making estimates of channel erosion. This calculation excludes the non-erosive hardened and piped sections of the stream.

8.7 Selection of a Representative Modeling Period

The selection of the modeling period was based on two factors; availability of streamflow data and the need to represent critical hydrological conditions and seasonal variability. A discussion of analysis conducted to select a representative period is given in Section 4.0.

8.8 Hydrologic Model Calibration Process

Hydrologic calibration was not performed for Back Creek or Toms Creek, as no suitable stream flow data existed within or nearby either watershed. The GWLF model was originally developed for use in ungaged watersheds and this was considered an acceptable alternative since both the impaired and reference watershed are located nearby allowing the use of the same weather data. The model's parameters were carefully assigned based on available soils, landuse, topographic data, and with guidance from the GWLF manual to adequately account for differences in watershed characteristics that affect hydrology, erosion and sediment transport.

8.9 Existing Conditions

A listing of parameters from the GWLF Transport input files that were finalized for existing conditions are given in Table 8.5 through Table 8.9. Watershed parameters for the Back Creek and reference watershed Toms Creek are given in Table 8.5.

Table 8.5 Back Creek and Reference Watershed Toms Creek GWLF Watershed parameters for existing conditions.

GWLF Watershed Parameter	Units	Back Creek	Toms Creek
Recession Coefficient	Day^{-1}	0.0325	0.0325
Seepage Coefficient	Day^{-1}	0.0002	0.0002
Sediment Delivery Ratio		0.11	0.11
Unsaturated Water Capacity	(cm)	9.7	18.18
Erosivity Coefficient (April-Sept.)		0.25	0.25
Erosivity Coefficient (Oct.-Mar)		0.06	0.06
% Developed land	(%)	0.55	1.6
Livestock density	(AU/ac)	0.1780	0.1076
Area-weighted soil erodibility		0.327	0.322
Area weighted runoff curve number		70.62	70.98
Total Stream Length	(m)	42996	21176
Mean channel depth	(m)	3.3	1.3

Monthly evaporation cover coefficients are listed in Table 8.6.

Table 8.6 Back Creek and Reference Watershed Toms Creek GWLF monthly evaporation cover coefficients for existing conditions.

Watershed	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Back Creek	0.68	0.93	0.88	0.87	0.87	0.92	0.92	0.57	0.50	0.70	0.73	0.71
Toms Creek	0.60	0.95	0.92	0.91	0.91	0.95	0.94	0.53	0.48	0.62	0.64	0.63

The area-weighted USLE erosion parameter and runoff curve number are listed by landuse (erosion source areas) in Table 8.7 for Back Creek and reference watershed Toms Creek.

Table 8.7 Back Creek and Reference Watershed Toms Creek GWLF landuse parameters for existing conditions.

Landuse Categories	Back Creek		Toms Creek	
	CN	KLSCP	CN	KLSCP
LDR-PER	70.58	0.00128	69.18	0.000698
HDR-PER	70.58	0.00128	70.62	0.000328
COM-PER	69.83	0.00079	67.71	0.000917
Transitional	86.05	0.13630	85.34	0.034843
Forest	72.59	0.11902	76.12	0.154224
Disturbed Forest	63.99	0.00149	68.80	0.001928
Urban Grass	63.99	0.01289	68.80	0.000000
Hay	68.05	0.00435	67.46	0.003159
Pasture 1	84.41	0.06529	84.10	0.047385
Pasture 2	76.73	0.03090	76.28	0.022429
Pasture 3	71.05	0.00566	70.46	0.004107
Stream Edge	87.09	0.13057	86.91	0.094770
High-tillage	79.67	0.24298	83.21	0.202833
Low-tillage	82.05	0.06640	79.89	0.055428
LDR-IMP	98.00	0.00000	98.00	0.000000
HDR-IMP	98.00	0.00128	98.00	0.000328
COM-IMP	98.00	0.00079	98.00	0.000917

The area adjustment for Back Creek reference watershed is listed in Table 8.8.

Table 8.8 Area Adjustment for Back Creek TMDL Reference Watershed Toms Creek.

Landuse Categories	Impaired Back Creek	Original Toms Creek	Reference (Area-adjusted) Toms Creek (x1.971204)
LDR-PER	12.562	87.838	173.146
HDR-PER	0.000	0.210	0.414
COM-PER	19.732	15.553	30.657
Transitional	9.540	27.570	54.350
Disturbed Forest	131.972	92.420	182.174
Forest	4,267.100	2,988.160	5,890.280
Urban Grass	0.000	0.000	0.000
Hay	476.859	150.946	297.545
Pasture 1	466.262	315.836	622.576
Pasture 2	1,631.916	315.836	622.576
Pasture 3	2,564.440	947.507	1,867.729
Stream Edge	158.953	12.898	25.425
High-tillage	108.453	59.933	118.139
Low-tillage	433.811	139.843	275.658
Water	5.724	3.816	7.522
LDR-IMP	3.752	53.836	106.122
HDR-IMP	0.000	0.172	0.339
Com-IMP	33.598	25.375	50.020

The existing sediment loads were modeled for Back Creek and Toms Creek and adjusted for agricultural BMPs applied to both watersheds as identified in the Virginia Agricultural BMP database (VADCR, 2004). The agricultural BMP database provides the type of BMP, acres benefited, sheet and rill erosion and gully erosion reduction. The total sediment reduction due to BMPs was calculated by multiplying the total erosion times the delivery ratio for the respective watersheds. An efficiency factor was then calculated based on the existing sediment load from agricultural land and agricultural category adjusted for BMPs.

The target TMDL load for Back Creek is the average annual load from the area-adjusted Toms Creek watershed under existing conditions (Table 8.9). The benthic TMDL for Back Creek includes three components –WLA, LA, and MOS.

Table 8.9 Existing sediment loads for Back Creek and reference watershed Toms Creek.

Sediment Sources		Back Creek		Toms Creek (Area adjusted)	
	Area (ha)	Sediment (T/yr)	Sediment (T/ha)	Sediment (T/yr)	Sediment (T/ha)
LDR-PER	12.562	0.261	0.021	1.825	0.011
HDR-PER	0.000	0.000	0.000	0.002	0.004
COM-PER	19.732	0.252	0.013	0.403	0.013
Transitional	9.540	32.047	3.359	46.435	0.854
Forest	4,267.100	74.855	0.018	169.234	0.029
Disturb. Forest	131.972	288.903	2.189	563.556	3.094
Hay	476.859	29.783	0.062	12.892	0.043
Pasture 1	466.262	736.189	1.579	710.487	1.141
Pasture 2	1,631.916	1,065.925	0.653	282.005	0.453
Pasture 3	2,564.440	241.744	0.094	125.128	0.067
Stream-Edge-Past	158.953	521.692	3.282	60.283	2.371
High Tillage	108.453	578.831	5.337	577.106	4.885
Low Tillage	433.811	667.976	1.540	340.029	1.234
LDR-IMP	3.752	0.757	0.202	21.422	0.202
HDR-IMP	0.000	0.000	0.000	0.068	0.202
COM-IMP	33.598	6.783	0.202	10.097	0.202
Water	5.724	0.000	0.000	0.000	0.000
NPS Loads		4,245.997		2,920.974	
BMP		-603.350		-83.500	
Channel Erosion		6,418.163	0.149	1,265.057	0.060
Point Source – Loads		0.280		0.000	
Watershed Totals	**10,324.673**	**10,060.810**		**4,102.532**	

9. ALLOCATION

Total Maximum Daily Loads consist of WLAs, LAs, including natural background levels. Additionally, the TMDL must include a MOS that either implicitly or explicitly accounts for uncertainties in the process (*e.g.,* landuses cover factors). For this study, the margin of safety was explicitly set to 10% to account for uncertainty in developing benthic TMDLs. The definition is typically denoted by the expression:

TMDL = WLAs + LAs + MOS

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving water body and still achieve water quality standards. For sediment, the TMDL is expressed in terms of metric tons or metric tons per hectare.

This section describes the development of benthic TMDLs for sediment for the Back Creek using a reference watershed approach. The model was run for existing conditions over the period January 1994 to March 2000. The average annual sediment load from reference watershed Toms Creek- area adjusted- was used to define the TMDL load for the Back Creek watershed. A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

9.1 Sensitivity Analysis

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.,* seasonal and spatial variability of crop cover conditions, runoff curve number, etc.). Sensitivity analyses were run on the watershed parameters listed in Table 9.1. For a given simulation, the model parameters in Table 9.1 were set at the base value except for the parameter being evaluated. Each parameter was evaluated through 10 and 50- percentage change, from the base value. The results show that the model is extremely sensitive to parameter changes resulting in major changes in either runoff or sediment (Table 9.2). For example, decreases in the runoff curve number (65) resulted in little change in channel erosion; however, the channel erosion output was extremely sensitive to increases in the curve number. The results tend to reiterate the importance of carefully evaluating conditions in the watershed and following a systematic protocol in establishing values for model parameters.

Table 9.1 Base watershed parameter values used to determine hydrologic and sediment response.

GWLF Watershed Parameter	Units	Base Value
Recession Coefficient	Day^{-1}	0.384
Seepage Coefficient	Day^{-1}	0.02
Unsaturated Water Capacity	(Cm)	10
Erosivity Coefficient (April – September)		0.26
Erosivity Coefficient (October - March)		0.06
% Developed land	(%)	10%
Livestock density	(AU/ac)	0.1785
Area weighted soil erodibility (K-factor)		0.28
Area weighted runoff curve number		65
Total Stream Length	(m)	684590
Mean Channel Depth	(m)	1.5

Table 9.2 Sensitivity of model response to change in selected parameters.

Model Parameter	Parameter Change	% Change in Runoff	% Change in Sediment Load	% Change in Channel Sediment Load
Recession Coefficient	-50	-50	-4.76	-11.4
Recession Coefficient	-10	-3	-0.06	-1.71
Recession Coefficient	10	3	9.6	1.92
Recession Coefficient	50	50	19	4.57
Seepage Coefficient	-50	17.1	0.06	0.002
Seepage Coefficient	-10	2.94	0.08	0.001
Seepage Coefficient	10	-2.74	-0.08	-0.001
Seepage Coefficient	50	-12.1	-0.35	-0.002
Unsaturated Water Capacity	-50	7.89	0.298	0.002
Unsaturated Water Capacity	-10	1	2.6	0.001
Unsaturated Water Capacity	10	-1	-2.5	-0.001
Unsaturated Water Capacity	50	4.2	-0.1	-0.002
Erosivity Coefficient (April – September)	-50	Insensitive	-39.7	-49
Erosivity Coefficient (April – September)	-10	Insensitive	-9.5	-11.9
Erosivity Coefficient (April – September)	10	Insensitive	9.58	11.2
Erosivity Coefficient (April – September)	50	Insensitive	48	51.6
% developed land	-50	Insensitive	insensitive	Insensitive
% Developed land	-10	Insensitive	Insensitive	Insensitive
% Developed land	10	Insensitive	Insensitive	Insensitive
% Developed land	50	Insensitive	Insensitive	Insensitive
No. of livestock	-50	Insensitive	Insensitive	Insensitive
No. of livestock	-10	Insensitive	Insensitive	Insensitive
No. of livestock	10	Insensitive	Insensitive	Insensitive
No. of livestock	50	Insensitive	Insensitive	Insensitive
Area weighted soil erodibility	-50	Insensitive	-50	Insensitive
Area weighted soil erodibility	-10	Insensitive	-10	Insensitive
Area weighted soil erodibility	10	Insensitive	10	Insensitive
Area weighted soil erodibility	50	Insensitive	10	55000
Area weighted runoff curve number	-50	-4.02	-1.20	Insensitive
Area weighted runoff curve number	-10	-1.5	-3.70	Insensitive
Area weighted runoff curve number	10	1.5	3.87	10700
Area weighted runoff curve number	50	4.02	1.23	143200
Total Stream Length	-50	Insensitive	Insensitive	-49
Total Stream Length	-10	Insensitive	Insensitive	-11.9
Total Stream Length	10	Insensitive	Insensitive	11.2
Total Stream Length	50	Insensitive	Insensitive	51.6
Mean Channel Depth	-50	Insensitive	Insensitive	-49
Mean Channel Depth	-10	Insensitive	Insensitive	-8.9
Mean Channel Depth	10	Insensitive	Insensitive	11.2
Mean Channel Depth	50	Insensitive	Insensitive	51.6

9.2 Back Creek Benthic TMDL

The Back Creek benthic TMDL was developed for sediment, with Toms Creek as the reference watershed. The area of Toms Creek was increased by the ratio of the impaired watershed area to the reference watershed area (1.97124). After adjustment, the Toms Creek reference watershed area equaled the Back Creek watershed area (10,324.673 ha). Landuse acreage for Toms Creek was reduced while maintaining the original landuse distribution.

The target TMDL load for Back Creek is the average annual load from the area-adjusted Toms Creek watershed under existing conditions (Table 9.3). The benthic TMDL for Back Creek includes three components –WLA, LA, and a MOS. The WLA was calculated as the sum of all permitted point source discharges. The LA was calculated as the target TMDL load minus the WLA load minus the MOS.

Table 9.3 TMDL Targets for Back Creek Watershed.

Impairment		WLA (T/yr)	LA (T/yr)	MOS (T/yr)	TMDL (T/yr)
Back Creek		**0.280**	**3,693**	**410**	**4,103**
VAR050140	0.242				
VPG120009	0.000				
VAG402033	0.019				
VAG402086	0.019				

[1] General permits – single family home.

9.2.1 Future Development

Development in the rural Back Creek watershed is not expected to be a significant issue over the next 25 years. A scenario including single-family homes built on 5-acre lots was run to assess possible impact on the TMDL. The scenario assumes that erosion control measures are in place during construction.

The following assumptions were used to arrive at the expected landuse change listed in Table 9.4. It was assumed that 2 new homes/yr would be built on 5 acre lots affecting a total of 1,012 hectares (2,500 areas) over a 25 year period. It was also assumed that the entrance roads would average 500 feet in length and 20 feet in width. The house building footprint and walkways would average 3,000 sq ft. The average disturbed area per household would be approximately 0.30 ha. Of the 1,012 ha affected, 80% of the area was assumed to remain in existing landuse (pasture and forest). The remaining 20% would be low density residential with 30% impervious and 70% pervious. Commercial growth was assumed to not exceed 20 ha. The existing commercial category is primarily due to Route 100 crossing the watershed. The future growth scenario resulted in the percentage developed land increasing from 0.55% to 1.2%. The projected future sediment loads for Back Creek based on scenarios in Table 9.4 are given in Table 9.5. The sediment load would be expected to increase by 986T/yr due to expected growth (Table 9.6).

Table 9.4 Summary of landuse scenario for 25-year projected growth.

Landuse	Existing	Projected	% Change
Forest	4,399.	4,288.0	-2.5
Pasture	5,298.3	5,187.3	-2.1
Transition	9.6	9.6	0
LDR	16.3	218.7	+217.7
COM	53	73	+37.7

Table 9.5 Projected future sediment loads for Back Creek.

Sediment Sources	Area (ha)	Back Creek Sediment (T/yr)	Sediment (T/ha)
LDR-PER	168.410	3.507	0.021
HDR-PER	0.000	0.000	0.000
COM-PER	27.132	0.346	0.013
Transitional	9.540	32.080	3.363
Forest	4,159.313	73.023	0.018
Disturb. Forest	128.639	281.911	2.191
Hay	466.859	29.183	0.063
Pasture 1	456.484	721.495	1.581
Pasture 2	1,597.695	1,044.630	0.654
Pasture 3	2,510.663	236.893	0.094
Stream-Edge-Past	155.620	511.282	3.285
High Tillage	108.455	579.451	5.342
Low Tillage	433.819	668.679	1.541
LDR-IMP	50.304	10.155	0.202
HDR-IMP	0.000	0.000	0.000
COM-IMP	46.199	9.326	0.202
Water	5.724	0.000	0.000
NPS Load		4,201.963	
BMP		-603.35	
Channel Erosion		7,448.921	0.173
WLA		0.280	
Watershed Totals	**10,324.860**	**11,047.812**	

The reductions required to meet the TMDL were based on the future growth conditions (Table 9.6). To aid the development of TMDL allocation scenarios, nonpoint source areas were grouped into agriculture, urban and forestry categories. Sub-categories for agriculture and forestry were also included to provide better definition of allocation within the broader groupings (Table 9.7). The predominant sediment loads are from agriculture (cropland, pasture and stream edge) and the stream channel. All other categories are already lower than the reference values.

Table 9.6 Required reductions for Back Creek Watershed.

Load Summary	Back Creek	Reductions Required	
		(T/yr)	(% of existing load)
Future Projected Load	11,048	7,355	73.1
Existing Load	10,061	6,368	63.3
TMDL	4,103		
Target Modeling Load	3,693		

Table 9.7 Comparison of grouped sediment loads for Back Creek with reference watershed Toms Creek.

Source Category	Future Conditions Back Creek (T/yr)	Reference Toms Creek (T/yr)
Agriculture	3,791.770	2,107.931
Hay	29.183	12.892
Cropland	1,248.130	917.135
Pastureland	2,003.175	1,117.620
Stream-Edge (access)	511.282	60.283
Urban	55.415	80.253
Forestry	354.935	732.790
Disturbed Forest	281.911	563.556
Channel Erosion	6,418.163	1,265.057
Point Source	0.280	0.000

Two sediment reduction alternatives are presented in Table 9.8. Alternative 1 requires sediment reductions from all agricultural areas (cropland 69%, pastureland 60%) and channel erosion (65.8%). The reductions could be achieved through riparian buffers, livestock exclusion from streams (which will help achieve reduction targets for a bacteria TMDL on the same stream segment), improving pasture, and reduced tillage. Alternative 2 shows reduction from cropland (90%), pastureland (69%), and channel erosion (60.1%).

Table 9.8 TMDL sediment allocation scenarios for the Back Creek impairment.

Sediment Source Categories	Existing Condition (T/yr)	Allocations Alternative 1 (%)	(T/yr)	Alternative 2 (%)	(T/yr)
LDR-PER	3.507		3.507		3.507
HDR-PER	0.000		0.000		0.000
COM-PER	0.346		0.346		0.346
Transitional	32.080		32.080		32.080
Forest	73.023		73.023		73.023
Disturbed Forest	281.911		281.911		281.911
Pastureland	**2,543.483**	**60**	**1,017.393**	**69**	**788.480**
Cropland	**1,248.130**	**69**	**386.920**	**90**	**124.813**
LDR-IMP	10.155		10.155		10.155
HDR-IMP	0.000		0.000		0.000
COM-IMP	9.326		9.326		9.326
Water	0.000		0.000		0.000
NPS Load	4,201.961		1,741.638		1,323.641
Active Ag. BMPs	-603.350		-603.350		-603.350
Channel Erosion	7,448.921	**65.8**	**2,547.531**	**60.1**	**2972.119**
WLA	0.280		0.280		0.280
Total	**11,047.812**		**3,686.099**		**3,692.690**
Target Allocation Load (TMDL-MOS-WLA)			**3,693.000**		**3,693.000**

PART IV: IMPLEMENTATION AND PUBLIC PARTICIPATION

10. IMPLEMENTATION

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria and benthic impairments on Back Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by the civilian State Water Control Board and then EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent *Guidance Manual for Total Maximum Daily Load Implementation Plans*, published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

10.1 Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice to control bacteria and minimize streambank erosion is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the direct cattle deposits and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock has been shown to reduce bank erosion. Improved pasture management including less intensive grazing, minimize animal concentrations by frequent movement of winter feeding areas, improving pasture forages, etc, can significantly reduce soil loss from pasture areas. Reducing tillage operations, farming on the contour, strip cropping, maintaining a winter cover crop, etc. have been demonstrated as effective measures to reduce erosion from cropland agriculture.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. *It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;*
2. *It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;*
3. *It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;*
4. *It helps ensure that the most cost effective practices are implemented first; and*
5. *It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.*

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage I scenarios are targeted at controllable, anthropogenic bacteria and sediment sources.

Stage I scenarios - Bacteria

The goal of the Stage I scenarios is to reduce the bacteria loadings from controllable sources, excluding wildlife. The Stage I scenarios were generated with the same model setup as was used for the TMDL allocation scenarios.

The Stage I water quality goal is to reduce the number of violations of the instantaneous standard to less than 10%. However, if the allocation scenario required to achieve this goal requires reductions in loads greater than 60% in land-based loads from urban and agricultural sources and any reductions in wildlife loads, then the Stage I allocation is defined as a 100% reduction in loads from sewer overflows and uncontrolled residential discharges (straight pipes), a 100% reduction in direct in-stream loads from livestock, 60% reduction in land-based loads from urban and agricultural sources and a 0% reduction in all wildlife loads. This is the case in Back Creek (Table 10.1, scenario 4).

Table 10.1 Reduction percentages for the Stage I implementation.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations	
	Direct Wildlife	NPS Wildlife	Direct Livestock	NPS Pasture / Livestock	Res./ Urban	Straight Pipe/ Sewer Overflow	GM > 126 cfu/ 100ml	Single Sample Exceeds 235 cfu/ 100ml
1	0	0	0	0	0	0	100	82.6
2	0	0	0	0	0	100	100	82.6
3	0	0	90	50	50	100	76.7	36.7
4	0	0	100	60	60	100	63.3	31.9
5	0	0	100	99	99	100	0.0	2.74
6	75	75	100	99	99	100	0.0	1.48
7	99	99.5	100	99.5	99.5	100	0.0	0.44
8	38	93	100	99.8	95	100	0.0	0.0

Table 10.2 details the load reductions required for meeting the Stage I Implementation.

Table 10.2 Nonpoint source allocations in the Back Creek impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Residential	7.15E+13	2.86E+13	60
Commercial	1.28E+12	5.12E+11	60
Barren	2.18E+11	8.72E+10	60
Cropland	4.51E+15	1.80E+15	60
Livestock Access	3.23E+14	1.29E+14	60
Pasture	4.34E+15	1.74E+15	60
Forest	2.97E+14	2.97E+14	0
Water	0.00E+00	0.00E+00	0
Direct			
Livestock	3.62E+15	0.00E+00	100
Wildlife	1.31E+13	1.31E+13	0
Straight Pipes	1.90E+11	0.00E+00	100

Stage I scenarios – Sediment

The Stage I goal was to reduce sediment loads in Back Creek to within 40% of target reductions. The target reduction goal during Stage I for Back Creek is 6,635 T/yr. The proposed management scenarios to achieve the Stage I water quality goals are summarized in Table 10.3.

Table 10.3 Management scenarios to achieve 60% of required sediment reductions for the Back Creek impairment.

Sediment Source Categories	Management Scenarios	Area/Length Affected ha : (m)	Existing Condition T/yr	Benefit T/ha : (T/m)	Implem. Condition T/yr
LDR-PER			3.507		3.507
HDR-PER			0.000		0.000
COM-PER			0.346		0.346
Transitional			32.080		32.080
Forest			73.023		73.023
Forest Disturbed			281.911		281.911
Pastureland	Pasture Improvement (improvement forage species, rotational grazing, reduced animal units per acre, minimize feeding areas with concentration of animals, etc.)	**1,000**	**2,543.483**	**1.487**	**1,056.483**
Cropland	High Tillage to Low Tillage (*e.g.*, no-tillage, strip cropping, rotations, minimal tillage)	**200**	**1,248.130**	**3.801**	**758.952**
LDR-IMP			10.155		10.155
HDR-IMP			0.000		0.000
COM-IMP			9.326		9.326
Water			0.000		0.000
NPS Load			4,201.961		2,225.783
Active Ag. BMPs			-603.350		-603.350
Channel Erosion	Riparian Buffer, Streambank stabilization, livestock exclusion.	**(28,970)**	**7,448.921**	**(0.173)**	**5,011.81**
WLA			0.280		0.280
Total			**11,047.812**		**6,634.523**
	Stage I Implementation Target (60% reduction)				**6,634.812**
	Target Allocation Load (TMDL-MOS-WLA)				**3,693.000**

The development of the implementation plan is expected to be an iterative process, with monitoring data refining its final design. Subsequent refinements will be made as the progress toward meeting milestones and the expressed TMDL goals is assessed. As practices are implemented, periodic analyses of water quality conditions will be conducted to evaluate the progress toward meeting end goals.

10.2 Link to Ongoing Restoration Efforts

Implementation of this TMDL will be integrated into on-going water quality improvement efforts aimed at restoring water quality in Back Creek and the New River basin. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of this effort. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of a nonpoint source implementation strategy.

The Town of Christiansburg is covered by existing VPDES permits for Phase II municipal separate storm sewer systems (MS4s), which covers over 40% of the headwaters of Back Creek. Recent MS4 permits have included language that recognizes that *"it is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs, and utilizing 40 CFR ξ122,44(k)"* which states that NPDES permit conditions may consist of *"Best management practices to control or abate the discharge of pollutants when:… (2) Numeric effluent limitations are infeasible…"*

10.3 Reasonable Assurance for Implementation

10.3.1 Follow-up Monitoring

VADEQ will continue monitoring the Back Creek watershed in accordance with its ambient watershed monitoring program to evaluate reductions in fecal bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards.

Monitoring station(s) on Back Creek will continue to be monitored. Watershed monitoring stations are designed to provide complete, census-based coverage of every watershed in Virginia. Two of the major data users in the Commonwealth (VADEQ and VADCR) have indicated that this is an important function for ambient water quality monitoring.

Watershed stations are located at the mouth and within the watershed, based on a census siting scheme. The number of stations in the watershed is determined by the NPS priority ranking thus focusing our resources on known problem areas. Watersheds are monitored on a rotating basis such that, in the 6-year assessment cycle, all 493 watersheds are monitored. These stations will be sampled at a frequency of once every other month for a two-year period on a 6-year rotating basin basis.

10.3.2 Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to *"develop and implement a plan to achieve fully supporting status for impaired waters"* (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 *Guidance for Water Quality-Based Decisions: The TMDL Process*. The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by the regional and local offices of VADEQ, VADCR, and other cooperating agencies.

Once developed, VADEQ will take TMDL implementation plans to the State Water Control Board (SWCB) for approval as the plan for implementing the pollutant allocations and reductions contained in the TMDLs. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP) in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

10.3.3 Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the VPDES Permit Regulation (9 VAC 25-31-10 et seq.). Section 9 VAC 25-31-120 describes the requirements for stormwater discharges. Also, federal regulations state in 40 CFR §122.44(k) that National Pollutant Discharge Elimination System (NPDES) permit conditions may consist of *"Best management practices to control or abate the discharge of pollutants when:… (2) Numeric effluent limitations are infeasible…"*.

There are currently no MS4 or stormwater permits in Back Creek.

10.3.4 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

10.3.5 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that, even after removal of all bacteria sources other than wildlife, the stream will not attain standards under all flow regimes at all times. As is the case for Back Creek, these streams may not be able to attain standards without some reduction in wildlife load. **Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.**

Although previous TMDLs for the Commonwealth have not addressed wildlife reductions in first stage goals, some localities have already introduced wildlife management practices. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria were approved by EPA and became effective in February 2004. Additional information can be found at http://www.deq.state.va.us/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This, and other, information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf.

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a Stage I scenario such as those presented previously in this chapter. The pollutant reductions in the Stage I scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the Stage I scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 10.1 above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the Stage I scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

11. PUBLIC PARTICIPATION

The development of the Back Creek TMDL greatly benefited from public involvement. Table 11.1 details the public participation throughout the project. The government kickoff meeting for the study of the Back Creek, Crab Creek, and Peak Creek watersheds took place on May 29, 2003 at the Dublin Library in Dublin, Virginia with 24 people (4 consultants, 14 government agents, 2 industry representatives, 2 from citizens' groups, and 2 farmers) attending. The kickoff meeting was publicized through direct mailing to local government agencies and a notice in the *Virginia Register*. The Agricultural Subcommittee met on July 8, 2003.

Stakeholders (12 farmers), VADEQ, and MapTech personnel met at New River Roundtable Agricultural subcommittee on August 9, 2003.

The first public meeting was held at the Dublin Town Hall in Dublin, Virginia on September 23, 2003 to discuss the process for TMDL development; 19 people (5 consultants, 9 government, 1 citizen group, 4 farmers/general public) attended. The meeting was publicized in the *Virginia Register* and copies of the presentation materials were available for public distribution. There was a 30 day-public comment period and no written comments were received.

A "Field Day" was offered on November 18, 2003 to all stakeholders in the Back Creek, Crab Creek, and Peak Creek watershed areas. There were 9 participants, including 5 citizens from the Back Creek area, 3 government agents, and 1 MapTech representative. Participants were shown examples of aquatic life from a nearby reference stream, then looked at 2 sites on Back Creek to contrast the differences and discuss potential implementation strategies. Field Day was announced at the first public meeting, and those interested were contacted by phone and email.

The final public meeting for the Back Creek, Crab Creek, and Peak Creek watersheds was held on March 17, 2004 at the New River Valley Competitiveness Center in Radford, Virginia. The meeting was publicized through 400 mailings to residents, in the Virginia Register, and on the VADEQ and MyChristiansburg.com websites. There were 25 attendees, including 8 citizens, 5 government agents, 7 MapTech representatives, and 5 from the general public. There was a 30 day-public comment period and no written comments were received.

Table 11.1 Public participation during TMDL development for the Back Creek watershed.

Date	Location	Attendance[1]	Type	Format
5/29/03	Dublin Library 300 Giles Avenue Dublin, VA	24	Kickoff Meeting[2]	Open to public at large
9/23/03	Dublin Town Hall 101 Dublin Park Road Dublin, VA	19	1st public	Open to public at large
11/18/03	Back Creek	9	Field Day[2]	Open to public at large
3/17/04	New River Valley Competitiveness Center 6580 Valley Center Drive Radford, VA	25	Final public[2]	Open to public at large

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.
[2]Combined meetings for Back Creek, Crab Creek, and Peak Creek.

Public participation during the implementation plan development process will include the formation of stakeholders' committee and open public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. A stakeholders' committee will have the expressed purpose of formulating the TMDL implementation plan. The major stakeholders were identified during the development of this TMDL. The committee will consist of, but not be limited to, representatives from VADEQ, VADCR, VDH, local agricultural community, local urban community, and local governments. This committee will have responsibility for identifying corrective actions that are founded in practicality, establish a time line to insure expeditious implementation, and set measurable goals and milestones for attaining water quality standards.

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GLOSSARY

Note: All entries in italics are taken from EPA (1998).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies*. Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity. *The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

Background levels*. Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria*. Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota. (2)

Biochemical Oxygen Demand (BOD). Represents the amount of oxygen consumed by bacteria as they break down organic matter in the water.

Biological Integrity. A water body's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional arganization comparable to that of similar natural, or non-impacted habitat.

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Causal analysis. A process in which data and other information are organized and evaluated using quantitative and logical techniques to determine the likely cause of an observed condition. (2)

Causal association. A correlation or other association between measures or observations of two entities or processes which occurs because of an underlying causal relationship. (2)

Causal mechanism. The process by which a cause induces an effect. (2)

Causal relationship. The relationship between a cause and its effect. (2)

Cause. 1. That which produces an effect (a general definition).
2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition). (2)

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Coefficient of determination. Represents the proportion of the total sample variability around y that is explained by the linear relationship between y and x. (In simple linear regression, it may also be computed as the square of the coefficient of correlation r.) (3)

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition. *Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also Respiration.*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Deterministic model. *A model that does not include built-in variability: same input will always result in the same output.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a* *compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion*. The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Dissolved Oxygen (DO). The amount of oxygen in water. DO is a measure of the amount of oxygen available for biochemical activity in a waterbody.

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Empirical model. *Use of statistical techniques to discern patterns or relationships underlying observed or measured data for large sample sets. Does not account for physical dynamics of waterbodies.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undersirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fate of pollutants. *Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

First-order kinetics. *The type of relationship describing a dynamic reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph. *A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Hyetograph. *Graph of rainfall rate versus time during a storm event.*

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause. (2)

Indirect effects. Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor. (2)

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA* *agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

Model. Mathematical representation of hydrologic and water quality processes. Effects of landuse, slope, soil characteristics, and management practices are included.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. *A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.*

Multivariate Regression. A functional relationship between 1 dependent variable and multiple independent variables that are often empirically determined from data and are used especially to predict values of one variable when given values of the others.

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nitrogen. An essential nutrient to the growth of organisms. Excessive amounts of nitrogen in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets. *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular landuse segment within a subwatershed (*e.g.,* pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Phosphorus. An essential nutrient to the growth of organisms. Excessive amounts of phosphorus in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25th, 50th, and 75th percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50th quartile is also known as the median. The 25th and 75th quartiles are referred to as the lower and upper quartiles, respectively.

Raw sewage. *Untreated municipal sewage.*

Rapid Bioassessment Protocol (RBP). A suite of measurements based on a quantitative assessment benthic microinvertebrates and a qualititative assessment of their habitat. RBP scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, landuse distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Reserve capacity. *Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence tim*e. Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles.

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquate systems as a result of erosion.

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and stormwater runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Simulation. *The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor. (2)

Spatial segmentation. *A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (*e.g.*, 200 cfu/100 ml geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (*i.e.*, a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Stepwise regression. All possible one-variable models of the form $E(y) = B_0 + B_1 x_1$ are fit and the "best" x_1 is selected based on the *t*-test for B_1. Next, two-variable models of the form $E(y) = B_0 + B_1 x_1 + B_2 x_i$ are fit (where x_i is the variable selected in the first step): the "second best" x_i is selected based on the test for B_2. The process continues in this fashion until no more "important" *x*'s can be added to the model. (3)

Storm runoff. *Stormwater runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Stressor. Any physical, chemical, or biological entity that can induce an adverse response. (2)

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Suspended Solids. Usually fine sediments and organic matter. Suspended solids limit sunlight penetration into the water, inhibit oxygen uptake by fish, and alter aquatic habitat.

Technology-based standards. *Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (*e.g.*,15-minutes, 1-hour, 1-day).

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Dissolved Solids (TDS). A measure of the concentration of dissolved inorganic chemicals in water.

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to renediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

TRC. Total Residual Chlorine. A measure of the effectiveness of chlorinating treated waste water effluent.

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Urban Runoff. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also* ***Domestic wastewater.***

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based effluent limitations (WQBEL). *Effluent limitations applied to dischargers when technology-based limitations alone would cause violations of water quality standards. Usually WQBELs are applied to discharges into small streams.*

Water quality-based permit. *A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

APPENDIX A

FREQUENCY ANALYSIS OF WATER QUALITY SAMPLING DATA

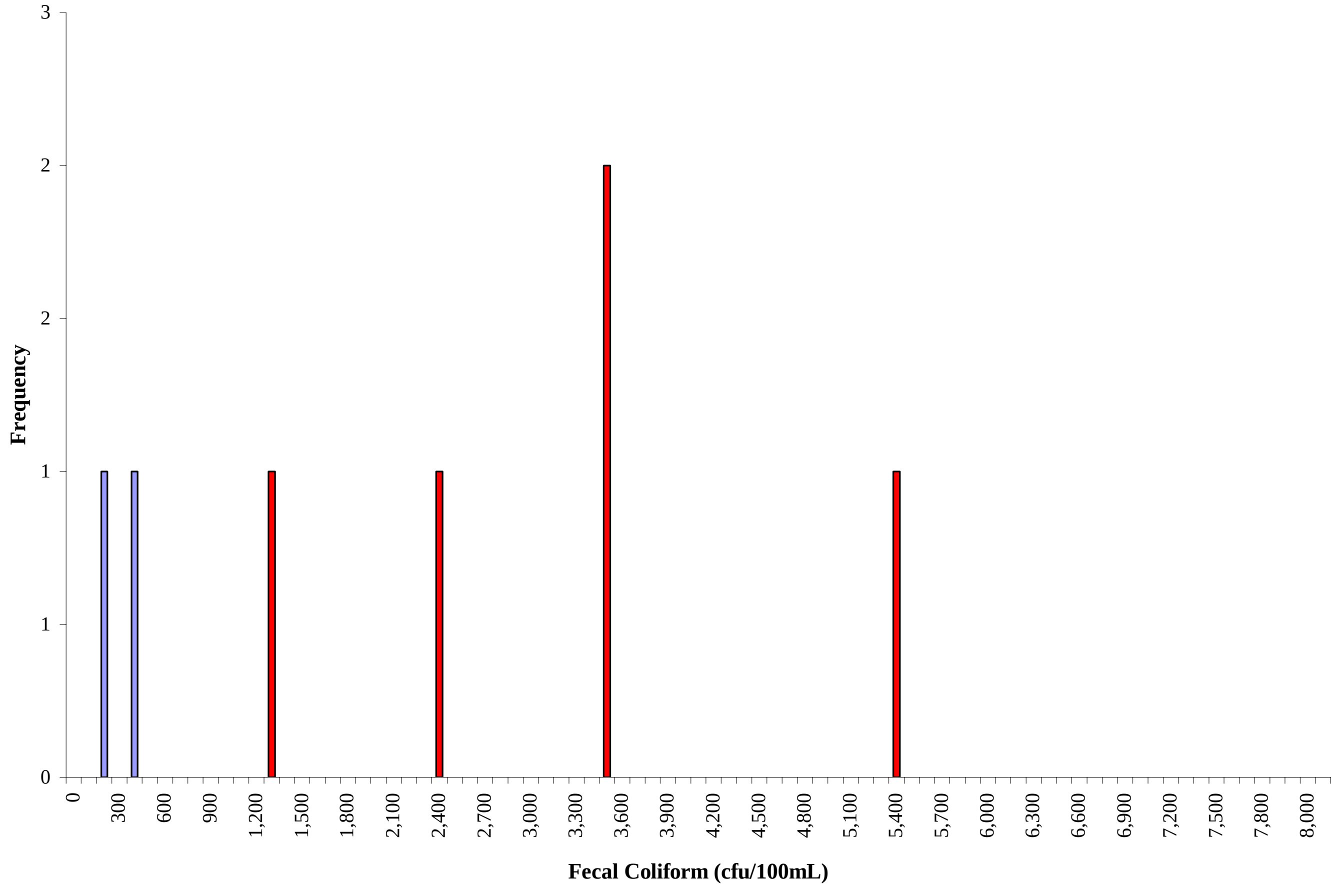

Figure A.1 Frequency analysis of fecal coliform concentrations at station 9-BCK000.74 in the Back Creek impairment for period August 2002 to August 2003.

*Red indicates a value, which violates the listing standard of 1,000 cfu/100 ml.

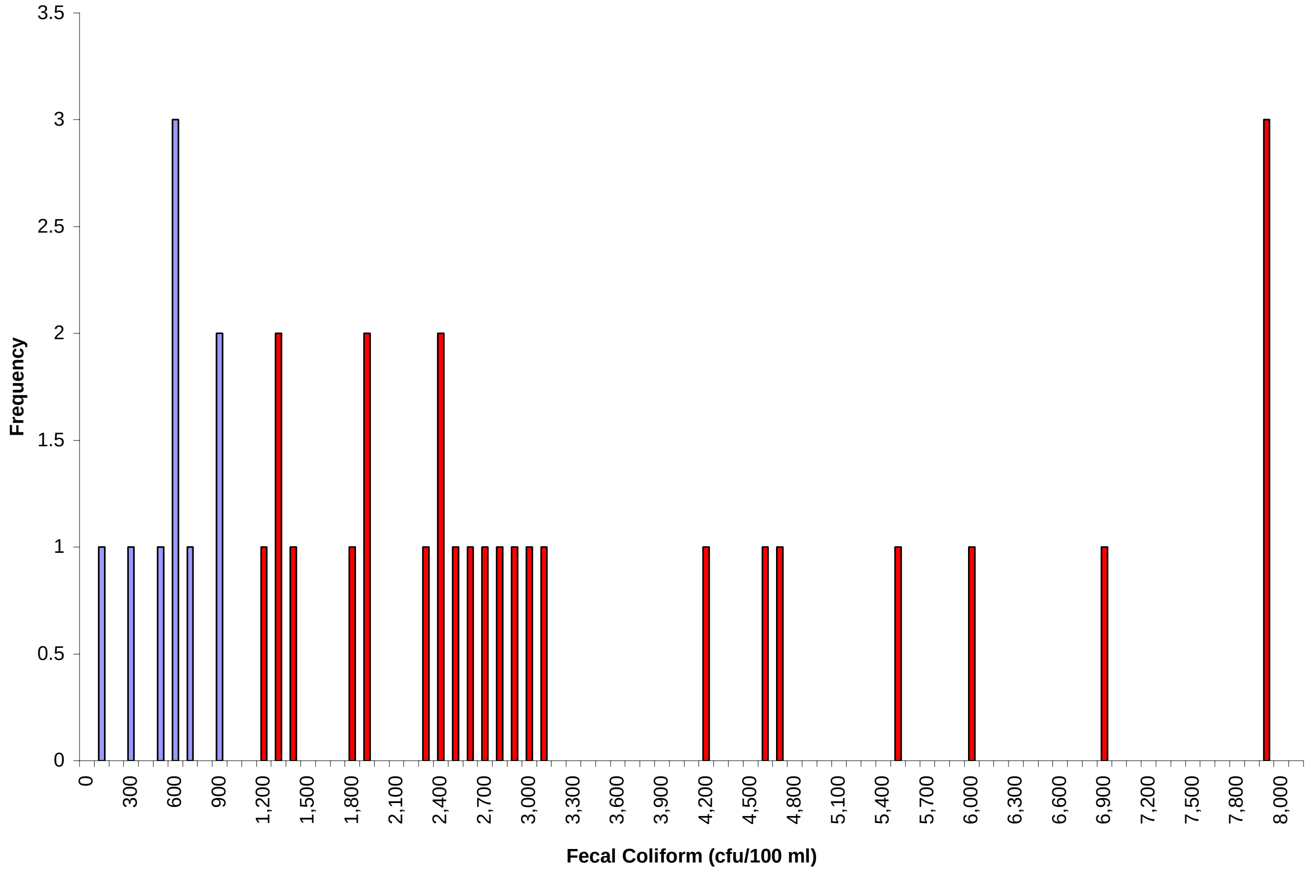

Figure A. 2 Frequency analysis of fecal coliform concentrations at station 9-BCK009.47 in the Back Creek impairment for period August 1992 to June 2001.

*Red indicates a value, which violates the listing standard of 1,000 cfu/100 ml.

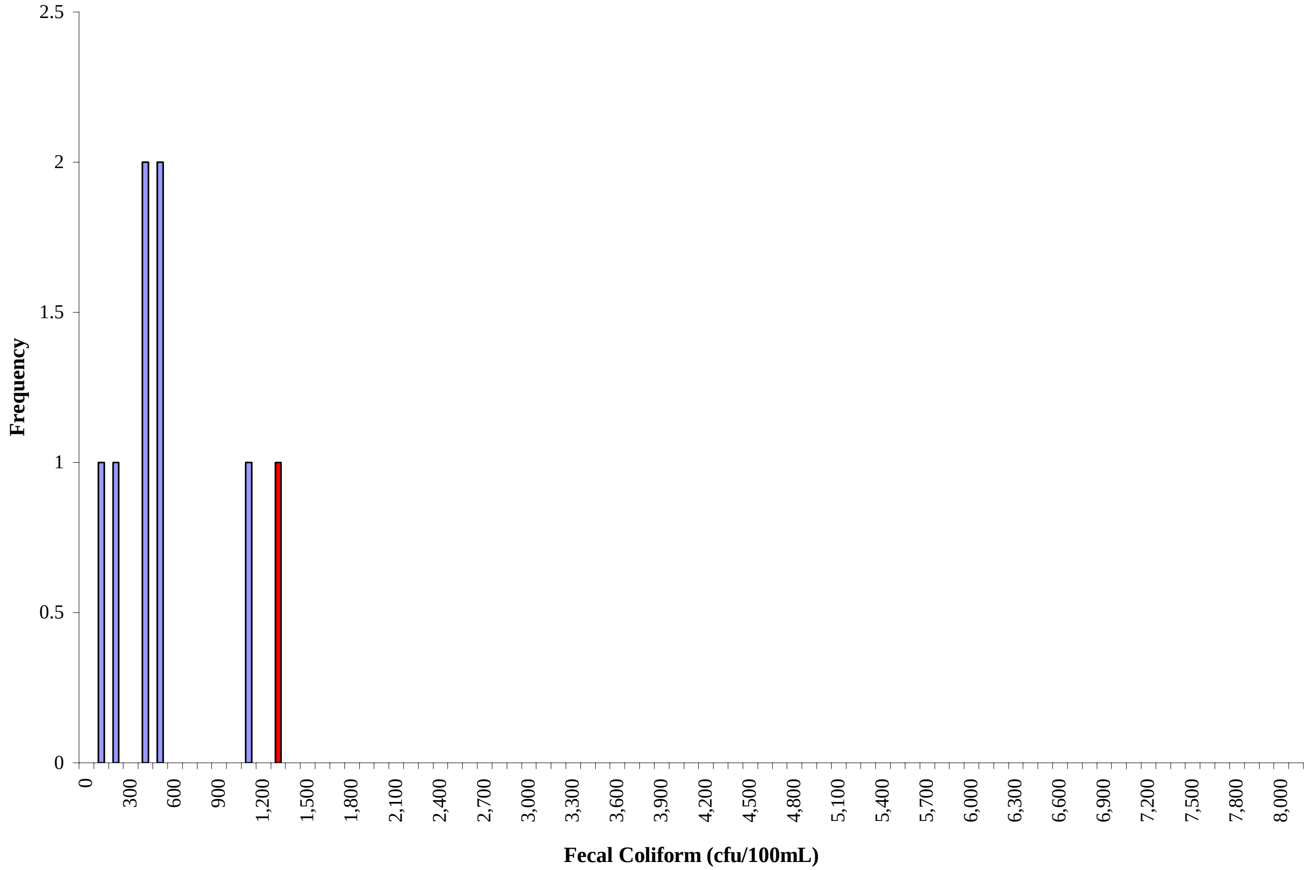

Figure A.3 Frequency analysis of fecal coliform concentrations at station 9-BCK015.98 in the Back Creek impairment for period August 2002 to October 2003.

*Red indicates a value, which violates the listing standard of 1,000 cfu/100 ml.

APPENDIX B

FECAL COLIFORM LOADS IN EXISTING CONDITIONS

Table B.1 Current conditions (2003) of land applied fecal coliform load for Back Creek impairment (Subsheds 19-23).

	Barren (cfu/ac*day)	Commercial (cfu/ac*day)	Forest (cfu/ac*day)	Pasture (cfu/ac*day)
January	1.12E+07	1.21E+07	3.81E+07	5.17E+09
February	1.12E+07	1.21E+07	3.81E+07	5.75E+09
March	1.12E+07	1.21E+07	3.81E+07	5.74E+09
April	1.12E+07	1.21E+07	3.81E+07	5.78E+09
May	1.12E+07	1.21E+07	3.81E+07	1.30E+12
June	1.12E+07	1.21E+07	3.81E+07	7.36E+09
July	1.12E+07	1.21E+07	3.81E+07	7.41E+09
August	1.12E+07	1.21E+07	3.81E+07	7.41E+09
September	1.12E+07	1.21E+07	3.81E+07	5.95E+09
October	1.12E+07	1.21E+07	3.81E+07	6.03E+09
November	1.12E+07	1.21E+07	3.81E+07	5.39E+09
December	1.12E+07	1.21E+07	3.81E+07	5.34E+09

Table B.1 Current conditions (2003) of land applied fecal coliform load for Back Creek impairment (Subsheds 19-23).

	Livestock Access (cfu/ac*day)	Residential (cfu/ac*day)	Row Crops (cfu/ac*day)	Water (cfu/ac*day)
January	2.18E+09	1.07E+11	1.38E+10	0.00E+00
February	2.39E+09	1.05E+11	1.61E+10	0.00E+00
March	3.57E+09	9.99E+10	1.56E+11	0.00E+00
April	4.95E+09	9.76E+10	1.56E+11	0.00E+00
May	4.95E+09	9.52E+10	1.56E+11	0.00E+00
June	6.13E+09	9.28E+10	6.31E+07	0.00E+00
July	6.13E+09	8.81E+10	6.31E+07	0.00E+00
August	6.13E+09	8.81E+10	6.31E+07	0.00E+00
September	4.95E+09	8.81E+10	4.58E+10	0.00E+00
October	3.57E+09	8.58E+10	1.56E+11	0.00E+00
November	3.27E+09	8.81E+10	1.56E+11	0.00E+00
December	2.18E+09	9.76E+10	1.38E+10	0.00E+00

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the Back Creek impairment (Subsheds 19-23).

Reach	Source	Jan cfu/day	Feb cfu/day	Mar cfu/day	Apr cfu/day	May cfu/day	Jun cfu/day
19	Human	3.18E+07	3.18E+07	3.18E+07	3.18E+07	3.18E+07	3.18E+07
	Livestock	1.68E+10	1.86E+10	2.90E+10	4.12E+10	4.12E+10	5.16E+10
	Wildlife	6.96E+09	6.96E+09	6.96E+09	6.96E+09	6.96E+09	6.96E+09
20	Human	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06
	Livestock	4.86E+10	5.42E+10	8.46E+10	1.20E+11	1.20E+11	1.51E+11
	Wildlife	1.44E+10	1.44E+10	1.44E+10	1.44E+10	1.44E+10	1.44E+10
21	Human	4.42E+08	4.42E+08	4.42E+08	4.42E+08	4.42E+08	4.42E+08
	Livestock	1.47E+10	1.64E+10	2.56E+10	3.64E+10	3.64E+10	4.56E+10
	Wildlife	8.15E+09	8.15E+09	8.15E+09	8.15E+09	8.15E+09	8.15E+09
22	Human	1.77E+07	1.77E+07	1.77E+07	1.77E+07	1.77E+07	1.77E+07
	Livestock	3.10E+10	3.45E+10	5.39E+10	7.67E+10	7.67E+10	9.61E+10
	Wildlife	4.36E+09	4.36E+09	4.36E+09	4.36E+09	4.36E+09	4.36E+09
23	Human	2.85E+07	2.85E+07	2.85E+07	2.85E+07	2.85E+07	2.85E+07
	Livestock	2.68E+09	2.98E+09	4.66E+09	6.63E+09	6.63E+09	8.32E+09
	Wildlife	1.94E+09	1.94E+09	1.94E+09	1.94E+09	1.94E+09	1.94E+09

Reach	Source	Jul cfu/day	Aug cfu/day	Sep cfu/day	Oct cfu/day	Nov cfu/day	Dec cfu/day
19	Human	3.18E+07	3.18E+07	3.18E+07	3.18E+07	3.18E+07	3.18E+07
	Livestock	5.16E+10	5.16E+10	4.12E+10	2.90E+10	2.64E+10	1.68E+10
	Wildlife	6.96E+09	6.96E+09	6.96E+09	6.96E+09	6.96E+09	6.96E+09
20	Human	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06
	Livestock	1.51E+11	1.51E+11	1.20E+11	8.46E+10	7.66E+10	4.86E+10
	Wildlife	1.44E+10	1.44E+10	1.44E+10	1.44E+10	1.44E+10	1.44E+10
21	Human	4.42E+08	4.42E+08	4.42E+08	4.42E+08	4.42E+08	4.42E+08
	Livestock	4.56E+10	4.56E+10	3.64E+10	2.56E+10	2.32E+10	1.47E+10
	Wildlife	8.15E+09	8.15E+09	8.15E+09	8.15E+09	8.15E+09	8.15E+09
22	Human	1.77E+07	1.77E+07	1.77E+07	1.77E+07	1.77E+07	1.77E+07
	Livestock	9.61E+10	9.61E+10	7.67E+10	5.39E+10	4.89E+10	3.10E+10
	Wildlife	4.36E+09	4.36E+09	4.36E+09	4.36E+09	4.36E+09	4.36E+09
23	Human	2.85E+07	2.85E+07	2.85E+07	2.85E+07	2.85E+07	2.85E+07
	Livestock	8.32E+09	8.32E+09	6.63E+09	4.66E+09	4.23E+09	2.68E+09
	Wildlife	1.94E+09	1.94E+09	1.94E+09	1.94E+09	1.94E+09	1.94E+09

Table B.3 Existing annual loads from land-based sources for the Back Creek impairment (Subsheds 19-23).

Source	Barren (cfu/yr)	Commercial (cfu/yr)	Forest (cfu/yr)	Pasture (cfu/yr)	Livestock Access l (cfu/yr)	Residential (cfu/yr)	Row Crop (cfu/yr)	Water (cfu/yr)
Pets								
Dogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.59E+13	0.00E+00	0.00E+00
Cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.29E+07	0.00E+00	0.00E+00
Total	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.59E+13	0.00E+00	0.00E+00
Human								
Failed Septic	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.39E+13	0.00E+00	0.00E+00
Livestock								
Dairy	0.00E+00	0.00E+00	0.00E+00	1.25E+15	7.32E+13	0.00E+00	4.45E+15	0.00E+00
Beef	0.00E+00	0.00E+00	0.00E+00	2.39E+15	1.28E+14	0.00E+00	0.00E+00	0.00E+00
Sheep	0.00E+00	0.00E+00	0.00E+00	1.20E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Goat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Horse	0.00E+00	0.00E+00	0.00E+00	1.37E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	0.00E+00	0.00E+00	0.00E+00	3.79E+15	2.01E+14	0.00E+00	4.45E+15	0.00E+00
Wildlife								
Raccoon	1.98E+11	1.01E+12	2.23E+14	3.13E+14	3.16E+13	1.21E+12	3.25E+13	0.00E+00
Muskrat	0.00E+00	1.61E+11	8.86E+12	1.45E+14	7.62E+13	3.21E+11	1.38E+13	0.00E+00
Deer	0.00E+00	0.00E+00	3.83E+13	4.39E+13	3.05E+12	3.45E+10	4.57E+12	0.00E+00
Turkey	2.14E+07	4.11E+07	2.14E+10	6.59E+09	6.61E+08	1.59E+07	5.43E+08	0.00E+00
Goose	6.99E+06	1.19E+08	2.51E+10	4.33E+10	2.75E+10	1.40E+08	4.70E+09	0.00E+00
Duck	2.57E+05	6.42E+06	1.08E+09	1.57E+09	8.33E+08	5.40E+06	2.11E+08	0.00E+00
Total	1.98E+11	1.17E+12	2.70E+14	4.29E+15	3.12E+14	7.14E+13	4.50E+15	0.00E+00

Table B.4 Existing annual loads from direct-deposition sources for the Back Creek impairment (Subsheds 19-23).

Source	Fecal Coliform Load (cfu/yr)
Human	
Straight Pipes	1.90E+11
Total	1.90E+11
Livestock	
Dairy	2.47E+15
Beef	1.08E+15
Swine	0.00E+00
Sheep	5.13E+12
Goat	0.00E+00
Horse	5.86E+13
Poultry	0.00E+00
Total	3.62E+15
Wildlife	
Raccoon	1.51E+12
Muskrat	1.15E+13
Beaver	9.13E+05
Deer	4.50E+10
Turkey	1.48E+07
Goose	2.59E+09
Duck	1.45E+08
Total	1.31E+13

APPENDIX C

UCI FILE USED FOR MODELING

```
PERLND
   ACTIVITY
    *** <PLS >               Active Sections                              ***
    *** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
      101  508    0    0    1    0    0    0    1    0    0    0    0    0
   END ACTIVITY

   PRINT-INFO
    *** < PLS>                       Print-flags                           PIVL  PYR
    *** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
      101  508    6    6    6    6    6    6    6    6    6    6    6    6    1    9
   END PRINT-INFO

   GEN-INFO
    ***             Name                  Unit-systems   Printer BinaryOut
    *** <PLS >                                t-series Engl Metr Engl Metr
    *** x -  x                                 in  out
      101     Water                             1    1    0    0    0    0
      102     Resid./Recr                       1    1    0    0    0    0
      103     Comm./Ind./Tr                     1    1    0    0    0    0
      104     Barren                            1    1    0    0    0    0
      105     Forest/Wet                        1    1    0    0    0    0
      106     Row Crops                         1    1    0    0    0    0
      107     Pasture/Hay                       1    1    0    0    0    0
      108     Pot. Liv. Acc.                    1    1    0    0    0    0
      201     Water                             1    1    0    0    0    0
      202     Resid./Recr                       1    1    0    0    0    0
      203     Comm./Ind./Tr                     1    1    0    0    0    0
      204     Barren                            1    1    0    0    0    0
      205     Forest/Wet                        1    1    0    0    0    0
      206     Row Crops                         1    1    0    0    0    0
      207     Pasture/Hay                       1    1    0    0    0    0
      208     Pot. Liv. Acc.                    1    1    0    0    0    0
      301     Water                             1    1    0    0    0    0
      302     Resid./Recr                       1    1    0    0    0    0
      303     Comm./Ind./Tr                     1    1    0    0    0    0
      304     Barren                            1    1    0    0    0    0
      305     Forest/Wet                        1    1    0    0    0    0
      306     Row Crops                         1    1    0    0    0    0
      307     Pasture/Hay                       1    1    0    0    0    0
      308     Pot. Liv. Acc.                    1    1    0    0    0    0
      401     Water                             1    1    0    0    0    0
      402     Resid./Recr                       1    1    0    0    0    0
      403     Comm./Ind./Tr                     1    1    0    0    0    0
      404     Barren                            1    1    0    0    0    0
      405     Forest/Wet                        1    1    0    0    0    0
      406     Row Crops                         1    1    0    0    0    0
      407     Pasture/Hay                       1    1    0    0    0    0
      408     Pot. Liv. Acc.                    1    1    0    0    0    0
      502     Resid./Recr                       1    1    0    0    0    0
      505     Forest/Wet                        1    1    0    0    0    0
      506     Row Crops                         1    1    0    0    0    0
      507     Pasture/Hay                       1    1    0    0    0    0
      508     Pot. Liv. Acc.                    1    1    0    0    0    0
   END GEN-INFO

   PWAT-PARM1
    *** <PLS >                   Flags
    *** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC  HWT IRRG
      101  508    0    1    1    1    1    1    0    0    1    1    0    0
   END PWAT-PARM1

   PWAT-PARM2
    *** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
    *** x  - x                (in)   (in/hr)      (ft)               (1/in)   (1/day)
      101             0.       2.0   0.21126       100     0.001      0.12     0.989
      102             1.       2.0   0.15120       800   0.05796      0.12     0.989
      103             1.       2.0   0.16414       777   0.03985      0.12     0.989
      104             0.       2.0   0.24750       789   0.05344      0.12     0.989
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  105            1.       2.0   0.23622      510   0.13221      0.12     0.989
  106            1.       2.0   0.19909      369     0.059      0.12     0.989
  107            0.       2.0   0.21224      354   0.05685      0.12     0.989
  108            1.       2.0   0.21531      100     0.001      0.12     0.989
  201            0.       2.0   0.16898      100     0.001      0.12     0.989
  202            1.       2.0   0.18361      800   0.02881      0.12     0.989
  203            1.       2.0   0.16743      800   0.04844      0.12     0.989
  204            0.       2.0   0.23413      694   0.10468      0.12     0.989
  205            1.       2.0   0.22303      429   0.10689      0.12     0.989
  206            1.       2.0   0.19391      472   0.04717      0.12     0.989
  207            0.       2.0   0.18635      472   0.05549      0.12     0.989
  208            1.       2.0   0.19547      100     0.001      0.12     0.989
  301            0.       2.0   0.15120      100     0.001      0.12     0.989
  302            1.       2.0   0.15120      637   0.04255      0.12     0.989
  303            1.       2.0   0.18059      800   0.07298      0.12     0.989
  304            0.       2.0   0.15120      101   0.15668      0.12     0.989
  305            1.       2.0   0.15422      454   0.15132      0.12     0.989
  306            1.       2.0   0.15575      457   0.10564      0.12     0.989
  307            0.       2.0   0.15559      495   0.06822      0.12     0.989
  308            1.       2.0   0.15392      100     0.001      0.12     0.989
  401            0.       2.0   0.15120      202     0.001      0.12     0.920
  402            1.       2.0   0.15120      578   0.08572      0.12     0.920
  403            1.       2.0   0.15120      553   0.03151      0.12     0.920
  404            0.       2.0   0.15345      508    0.0296      0.12     0.920
  405            1.       2.0   0.15305      100   0.09912      0.12     0.920
  406            1.       2.0   0.18026      100   0.10638      0.12     0.920
  407            0.       2.0   0.19938      342   0.08254      0.12     0.920
  408            1.       2.0   0.19720      672     0.001      0.12     0.920
  502            1.       2.0   0.24750      483    0.1825      0.12     0.989
  505            1.       2.0   0.21800      438   0.09382      0.12     0.989
  506            1.       2.0   0.16923      384   0.07613      0.12     0.989
  507            0.       2.0   0.16344      420    0.0977      0.12     0.989
  508            1.       2.0   0.16262      100     0.001      0.12     0.989
  END PWAT-PARM2

  PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
*** x  - x   (deg F)   (deg F)
  101  308       40.       35.        2.        2.      0.20    0.0325        0.
  401  508       40.       35.        2.        2.      0.35    0.0325        0.
  END PWAT-PARM3

  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                       (1/day)
  101  508       0.1     1.128       0.2      1.00       0.3       0.1
  END PWAT-PARM4

  PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  101  508      0.01      0.01       0.3      0.01       1.5      0.01      0.01
  END PWAT-STATE1

  MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     0.0100.0100.0100.3600.3600.0150.0100.0100.0100.0100.0100.010
  102     0.0140.0140.0150.0210.0210.0540.0440.0590.0590.0150.0150.014
  103     0.0140.0140.0150.0210.0210.0540.0440.0590.0590.0150.0150.014
  104     0.0110.0110.0110.0210.0210.0520.0430.0570.0570.0230.0210.010
  105     0.0840.0840.0840.1620.1620.3600.3230.3600.3600.1710.1550.042
  106     0.0970.0970.0970.1890.1890.3600.3600.3600.3600.2000.1820.049
  107     0.0770.0770.0770.1360.1820.2930.2590.2590.2590.1080.0410.039
  108     0.0770.0770.0770.1360.1820.2930.2590.2590.2590.1080.0410.039
  201     0.0100.0100.0100.3600.3600.0150.0100.0100.0100.0100.0100.010
  202     0.0140.0140.0150.0210.0210.0540.0440.0590.0590.0150.0150.014
  203     0.0140.0140.0150.0210.0210.0540.0440.0590.0590.0150.0150.014
  204     0.0110.0110.0110.0210.0210.0520.0430.0570.0570.0230.0210.010
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  205     0.0840.0840.0840.1620.1620.3600.3230.3600.3600.1710.1550.042
  206     0.0970.0970.0970.1890.1890.3600.3600.3600.3600.2000.1820.049
  207     0.0770.0770.0770.1360.1820.2930.2590.2590.2590.1080.0410.039
  208     0.0770.0770.0770.1360.1820.2930.2590.2590.2590.1080.0410.039
  301     0.0100.0100.0100.3600.3600.0150.0100.0100.0100.0100.0100.010
  302     0.0140.0140.0150.0210.0210.0540.0440.0590.0590.0150.0150.014
  303     0.0140.0140.0150.0210.0210.0540.0440.0590.0590.0150.0150.014
  304     0.0110.0110.0110.0210.0210.0520.0430.0570.0570.0230.0210.010
  305     0.0840.0840.0840.1620.1620.3600.3230.3600.3600.1710.1550.042
  306     0.0970.0970.0970.1890.1890.3600.3600.3600.3600.2000.1820.049
  307     0.0770.0770.0770.1360.1820.2930.2590.2590.2590.1080.0410.039
  308     0.0770.0770.0770.1360.1820.2930.2590.2590.2590.1080.0410.039
  401     0.0150.0150.0150.4000.4000.0260.0150.0150.0150.0100.0100.015
  402     0.0240.0240.0260.0350.0350.0900.0740.0980.0980.0200.0200.023
  403     0.0240.0240.0260.0350.0350.0900.0740.0980.0980.0200.0200.023
  404     0.0180.0180.0180.0350.0350.0870.0720.0950.0950.0310.0280.015
  405     0.1400.1400.1400.2700.2700.4000.4000.4000.4000.2280.2070.071
  406     0.1620.1620.1620.3150.3150.4000.4000.4000.4000.2660.2420.081
  407     0.1280.1280.1280.2270.3030.4000.4000.4000.4000.1440.0550.065
  408     0.1280.1280.1280.2270.3030.4000.4000.4000.4000.1440.0550.065
  502     0.0140.0140.0150.0210.0210.0540.0440.0590.0590.0150.0150.014
  505     0.0840.0840.0840.1620.1620.3600.3230.3600.3600.1710.1550.042
  506     0.0970.0970.0970.1890.1890.3600.3600.3600.3600.2000.1820.049
  507     0.0770.0770.0770.1360.1820.2930.2590.2590.2590.1080.0410.039
  508     0.0770.0770.0770.1360.1820.2930.2590.2590.2590.1080.0410.039
  END MON-INTERCEP

  MON-UZSN
*** <PLS >  Upper zone storage at start of each month  (inches)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     1.1101.1101.1101.9801.9801.9801.6591.6721.6720.6690.6690.669
  102     0.9440.9440.9761.7561.8091.8091.5091.5121.5120.4880.4740.474
  103     0.9120.9120.9431.6961.7491.7491.4611.4611.4610.4700.4560.456
  104     0.6620.6620.6911.2441.6211.6211.3521.3531.3530.3450.3320.332
  105     0.7800.7800.8151.4661.9121.9121.5931.5951.5950.4070.3900.390
  106     0.1750.1700.5781.5242.0002.0002.0002.0002.0000.7880.4700.131
  107     1.1051.1051.1482.0002.0002.0001.7851.7851.7850.5740.5530.553
  108     1.1151.1151.1562.0002.0002.0001.7991.8011.8010.5770.5570.557
  201     1.0181.0181.0181.8151.8151.8151.5211.5331.5330.6130.6130.613
  202     1.0251.0251.0591.9061.9621.9621.6371.6411.6410.5290.5140.514
  203     0.9550.9550.9871.7761.8311.8311.5301.5301.5300.4920.4780.478
  204     0.7090.7090.7401.3321.7361.7361.4471.4491.4490.3690.3550.355
  205     0.8410.8410.8801.5822.0002.0001.7191.7211.7210.4390.4210.421
  206     0.1730.1680.5711.5062.0002.0002.0002.0002.0000.7780.4640.129
  207     1.0361.0361.0761.9352.0002.0001.6741.6741.6740.5380.5180.518
  208     1.0651.0651.1051.9872.0002.0001.7191.7211.7210.5520.5330.533
  301     0.9690.9690.9691.7281.7281.7281.4481.4591.4590.5840.5840.584
  302     0.9440.9440.9761.7561.8091.8091.5091.5121.5120.4880.4740.474
  303     1.0171.0171.0521.8911.9511.9511.6291.6291.6290.5240.5090.509
  304     0.8130.8130.8491.5281.9911.9911.6601.6621.6620.4240.4070.407
  305     0.8190.8190.8571.5412.0002.0001.6741.6761.6760.4270.4100.410
  306     0.1550.1510.5121.3512.0002.0002.0002.0002.0000.6980.4170.116
  307     0.9490.9490.9861.7731.8401.8401.5341.5341.5340.4930.4750.475
  308     0.9450.9450.9811.7631.8321.8321.5261.5281.5280.4900.4730.473
  401     1.2111.2111.2112.0002.0002.0001.8101.8241.8240.7300.7300.730
  402     1.1801.1801.2202.0002.0002.0001.8861.8901.8900.6100.5930.593
  403     1.1801.1801.2202.0002.0002.0001.8901.8901.8900.6090.5900.590
  404     1.0161.0161.0611.9092.0002.0002.0002.0002.0000.5300.5090.509
  405     1.0151.0151.0631.9102.0002.0002.0002.0002.0000.5300.5080.508
  406     0.1800.1750.5941.5662.0002.0002.0002.0002.0000.8090.4830.135
  407     1.2891.2891.3382.0002.0002.0002.0002.0002.0000.6690.6440.644
  408     1.3331.3331.3832.0002.0002.0002.0002.0002.0000.6900.6660.666
  502     0.7690.7690.7941.4301.4731.4731.2291.2311.2310.3970.3860.386
  505     0.7160.7160.7491.3471.7561.7561.4631.4651.4650.3740.3580.358
  506     0.1510.1470.4981.3142.0002.0002.0002.0002.0000.6790.4050.113
  507     0.9450.9450.9811.7651.8311.8311.5271.5271.5270.4910.4730.473
  508     0.9530.9530.9881.7761.8461.8461.5371.5391.5390.4930.4760.476
  END MON-UZSN
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  MON-MANNING
*** <PLS >  Manning's n at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  102     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  103     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  104     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  105     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  106     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  107     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  108     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  201     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  202     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  203     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  204     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  205     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  206     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  207     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  208     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  301     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  302     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  303     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  304     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  305     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  306     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  307     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  308     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  401     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  402     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  403     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  404     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  405     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  406     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  407     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  408     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  502     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  505     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  506     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  507     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  508     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  END MON-MANNING

  MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  102     0.1000.1000.1000.1300.1300.1730.1000.1000.1000.1000.1000.100
  103     0.1000.1000.1000.1300.1300.1730.1000.1000.1000.1000.1000.100
  104     0.1000.1000.1000.1000.1120.1250.1000.1000.1000.1000.1000.100
  105     0.5760.5760.5840.7110.8100.8100.3920.3920.3270.6540.4800.576
  106     0.2580.2580.2930.3850.5530.8100.3420.3420.2840.4670.2150.258
  107     0.4390.4390.4560.5670.6760.7770.3280.3280.2730.3660.3660.439
  108     0.4390.4390.4560.5670.6760.7770.3280.3280.2730.3660.3660.439
  201     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  202     0.1000.1000.1000.1300.1300.1730.1000.1000.1000.1000.1000.100
  203     0.1000.1000.1000.1300.1300.1730.1000.1000.1000.1000.1000.100
  204     0.1000.1000.1000.1000.1120.1250.1000.1000.1000.1000.1000.100
  205     0.5760.5760.5840.7110.8100.8100.3920.3920.3270.6540.4800.576
  206     0.2580.2580.2930.3850.5530.8100.3420.3420.2840.4670.2150.258
  207     0.4390.4390.4560.5670.6760.7770.3280.3280.2730.3660.3660.439
  208     0.4390.4390.4560.5670.6760.7770.3280.3280.2730.3660.3660.439
  301     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  302     0.1000.1000.1000.1300.1300.1730.1000.1000.1000.1000.1000.100
  303     0.1000.1000.1000.1300.1300.1730.1000.1000.1000.1000.1000.100
  304     0.1000.1000.1000.1000.1120.1250.1000.1000.1000.1000.1000.100
  305     0.5760.5760.5840.7110.8100.8100.3920.3920.3270.6540.4800.576
  306     0.2580.2580.2930.3850.5530.8100.3420.3420.2840.4670.2150.258
  307     0.4390.4390.4560.5670.6760.7770.3280.3280.2730.3660.3660.439
  308     0.4390.4390.4560.5670.6760.7770.3280.3280.2730.3660.3660.439
```

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  401     0.1500.1500.1500.1500.1500.1500.1500.1500.1500.1000.1000.150
  402     0.1500.1500.1500.2160.2160.2880.1500.1500.1500.1000.1000.150
  403     0.1500.1500.1500.2160.2160.2880.1500.1500.1500.1000.1000.150
  404     0.1500.1500.1500.1590.1860.2090.1500.1500.1500.1160.1000.150
  405     0.9000.9000.9000.9000.9000.9000.6540.6540.6540.8720.6400.900
  406     0.4310.4310.4890.6420.9000.9000.5700.5700.5690.6220.2870.431
  407     0.7320.7320.7610.9000.9000.9000.5460.5460.5460.4880.4880.732
  408     0.7320.7320.7610.9000.9000.9000.5460.5460.5460.4880.4880.732
  502     0.1000.1000.1000.1300.1300.1730.1000.1000.1000.1000.1000.100
  505     0.5760.5760.5840.7110.8100.8100.3920.3920.3270.6540.4800.576
  506     0.2580.2580.2930.3850.5530.8100.3420.3420.2840.4670.2150.258
  507     0.4390.4390.4560.5670.6760.7770.3280.3280.2730.3660.3660.439
  508     0.4390.4390.4560.5670.6760.7770.3280.3280.2730.3660.3660.439
  END MON-LZETPARM

  NQUALS
*** x -  xNQUAL
  101  508    1
  END NQUALS

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
  101  508   FECAL COLIFO    #    0    0    0    1    1    1    0    0    0
  END QUAL-PROPS

  QUAL-INPUT
***            SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC
*** <PLS >  qty/ac qty/ton qty/ton    qty/  qty/ac   in/hr qty/ft3 qty/ft3
*** x -  x                          ac.day
  101         0.00    0.00    0.00    0.00    0.00   0.000   00.00    0.00
  102         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  103         0.00    0.00    0.00    0.00    0.00   0.100   00.00    0.00
  104         0.00    0.00    0.00    0.00    0.00   0.100   00.00    0.00
  105         0.00    0.00    0.00    0.00    0.00   0.450   00.00    0.00
  106         0.00    0.00    0.00    0.00    0.00   0.250   00.00    0.00
  107         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  108         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  201         0.00    0.00    0.00    0.00    0.00   0.000   00.00    0.00
  202         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  203         0.00    0.00    0.00    0.00    0.00   0.100   00.00    0.00
  204         0.00    0.00    0.00    0.00    0.00   0.100   00.00    0.00
  205         0.00    0.00    0.00    0.00    0.00   0.450   00.00    0.00
  206         0.00    0.00    0.00    0.00    0.00   0.250   00.00    0.00
  207         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  208         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  301         0.00    0.00    0.00    0.00    0.00   0.000   00.00    0.00
  302         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  303         0.00    0.00    0.00    0.00    0.00   0.100   00.00    0.00
  304         0.00    0.00    0.00    0.00    0.00   0.100   00.00    0.00
  305         0.00    0.00    0.00    0.00    0.00   0.450   00.00    0.00
  306         0.00    0.00    0.00    0.00    0.00   0.250   00.00    0.00
  307         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  308         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  401         0.00    0.00    0.00    0.00    0.00   0.000   00.00    0.00
  402         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  403         0.00    0.00    0.00    0.00    0.00   0.100   00.00    0.00
  404         0.00    0.00    0.00    0.00    0.00   0.100   00.00    0.00
  405         0.00    0.00    0.00    0.00    0.00   0.450   00.00    0.00
  406         0.00    0.00    0.00    0.00    0.00   0.250   00.00    0.00
  407         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  408         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  502         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  505         0.00    0.00    0.00    0.00    0.00   0.450   00.00    0.00
  506         0.00    0.00    0.00    0.00    0.00   0.250   00.00    0.00
  507         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  508         0.00    0.00    0.00    0.00    0.00   0.125   00.00    0.00
  END QUAL-INPUT
```

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  MON-ACCUM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  102     23E0823E0822E0821E0821E0820E0819E0819E0819E0818E0819E0821E08
  103     47E0647E0647E0647E0647E0647E0647E0647E0647E0647E0647E0647E06
  104     13E0613E0613E0613E0613E0613E0613E0613E0613E0613E0613E0613E06
  105     64E0664E0664E0664E0664E0664E0664E0664E0664E0664E0664E0664E06
  106     20E0823E0802E1002E1002E1002E0802E0802E0861E0802E1002E1020E08
  107     12E0813E0813E0813E0813E0816E0816E0816E0813E0814E0812E0812E08
  108     08E0808E0810E0812E0812E0814E0814E0814E0812E0810E0809E0808E08
  201     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  202     04E1004E1004E1004E1004E1004E1003E1003E1003E1003E1003E1004E10
  203     79E0679E0679E0679E0679E0679E0679E0679E0679E0679E0679E0679E06
  204     39E0639E0639E0639E0639E0639E0639E0639E0639E0639E0639E0639E06
  205     57E0657E0657E0657E0657E0657E0657E0657E0657E0657E0657E0657E06
  206     24E0828E0803E1003E1003E1091E0691E0691E0677E0803E1003E1024E08
  207     11E0812E0812E0812E0812E0815E0816E0816E0813E0813E0812E0811E08
  208     08E0808E0811E0813E0813E0816E0816E0816E0813E0811E0810E0808E08
  301     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  302     59E0857E0854E0853E0851E0850E0847E0847E0847E0845E0847E0853E08
  303     39E0639E0639E0639E0639E0639E0639E0639E0639E0639E0639E0639E06
  304     46E0646E0646E0646E0646E0646E0646E0646E0646E0646E0646E0646E06
  305     88E0688E0688E0688E0688E0688E0688E0688E0688E0688E0688E0688E06
  306     25E0829E0803E1003E1003E1002E0802E0802E0881E0803E1003E1025E08
  307     12E0813E0813E0813E0813E0816E0816E0816E0813E0813E0812E0812E08
  308     12E0812E0814E0817E0817E0819E0819E0819E0817E0814E0814E0812E08
  401     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  402     06E1006E1006E1006E1006E1005E1005E1005E1005E1005E1005E1006E10
  403     20E0620E0620E0620E0620E0620E0620E0620E0620E0620E0620E0620E06
  404     25E0625E0625E0625E0625E0625E0625E0625E0625E0625E0625E0625E06
  405     78E0678E0678E0678E0678E0678E0678E0678E0678E0678E0678E0678E06
  406     36E0842E0804E1004E1004E1001E0801E0801E0801E1004E1004E1036E08
  407     11E0812E0812E0812E0812E0815E0815E0815E0812E0812E0811E0811E08
  408     07E0808E0811E0814E0814E0817E0817E0817E0814E0811E0810E0807E08
  502     02E1002E1002E1002E1002E1002E1002E1002E1002E1002E1002E1002E10
  505     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  506     39E0845E0804E1004E1004E1002E0802E0802E0801E1004E1004E1039E08
  507     12E0813E0813E0813E0813E0816E0816E0816E0814E0814E0813E0812E08
  508     16E0816E0818E0821E0821E0824E0824E0824E0821E0818E0818E0816E08
  END MON-ACCUM

  MON-SQOLIM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  102     05E1005E1007E1011E1010E1010E1009E1009E1009E1005E1004E1004E10
  103     09E0809E0814E0823E0823E0823E0823E0823E0823E0814E0809E0809E08
  104     03E0803E0804E0806E0806E0806E0806E0806E0806E0804E0803E0803E08
  105     13E0813E0819E0832E0832E0832E0832E0832E0832E0819E0813E0813E08
  106     04E1005E1062E1001E1201E1276E0876E0876E0831E1062E1041E1004E10
  107     02E1003E1004E1007E1007E1008E1008E1008E1007E1004E1002E1002E10
  108     02E1002E1003E1006E1006E1007E1007E1007E1006E1003E1002E1002E10
  201     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  202     85E1083E1001E1202E1202E1202E1202E1202E1202E1299E1068E1077E10
  203     16E0816E0824E0839E0839E0839E0839E0839E0839E0824E0816E0816E08
  204     08E0808E0812E0820E0820E0820E0820E0820E0820E0812E0808E0808E08
  205     11E0811E0817E0828E0828E0828E0828E0828E0828E0817E0811E0811E08
  206     05E1006E1078E1001E1201E1245E0845E0845E0839E1078E1052E1005E10
  207     02E1002E1004E1006E1006E1008E1008E1008E1006E1004E1002E1002E10
  208     02E1002E1003E1007E1007E1008E1008E1008E1007E1003E1002E1002E10
  301     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  302     12E1011E1016E1026E1026E1025E1023E1023E1023E1014E1009E1011E10
  303     08E0808E0812E0819E0819E0819E0819E0819E0819E0812E0808E0808E08
  304     09E0809E0814E0823E0823E0823E0823E0823E0823E0814E0809E0809E08
  305     18E0818E0827E0844E0844E0844E0844E0844E0844E0827E0818E0818E08
  306     05E1006E1082E1001E1201E1277E0877E0877E0841E1082E1054E1005E10
  307     02E1003E1004E1006E1006E1008E1008E1008E1007E1004E1002E1002E10
  308     02E1002E1004E1008E1008E1010E1010E1010E1008E1004E1003E1002E10
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  401     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  402     01E1201E1202E1203E1203E1203E1203E1203E1203E1201E1201E1201E12
  403     04E0804E0806E0810E0810E0810E0810E0810E0810E0806E0804E0804E08
  404     05E0805E0808E0813E0813E0813E0813E0813E0813E0808E0805E0805E08
  405     16E0816E0823E0839E0839E0839E0839E0839E0839E0823E0816E0816E08
  406     07E1008E1001E1202E1202E1250E0850E0850E0859E1001E1280E1007E10
  407     02E1002E1004E1006E1006E1008E1008E1008E1006E1004E1002E1002E10
  408     01E1002E1003E1007E1007E1008E1008E1008E1007E1003E1002E1001E10
  502     46E1045E1064E1001E1201E1298E1092E1092E1092E1053E1037E1041E10
  505     27E0827E0840E0866E0866E0866E0866E0866E0866E0840E0827E0827E08
  506     08E1009E1001E1202E1202E1299E0899E0899E0863E1001E1285E1008E10
  507     02E1003E1004E1007E1007E1008E1008E1008E1007E1004E1003E1002E10
  508     03E1003E1006E1011E1011E1012E1012E1012E1011E1006E1004E1003E10
  END MON-SQOLIM

END PERLND

IMPLND
  ACTIVITY
*** <ILS >               Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
  101  501    0    0    1    0    0    1
  END ACTIVITY

  PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  101  501    6    6    6    6    6    6    1    9
  END PRINT-INFO

  GEN-INFO
***             Name             Unit-systems   Printer BinaryOut
*** <ILS >                           t-series Engl Metr Engl Metr
*** x -  x                            in  out
  101     Resid./Recr                  1    1    0    0    0    0
  102     Comm./Ind./Tr                1    1    0    0    0    0
  201     Resid./Recr                  1    1    0    0    0    0
  202     Comm./Ind./Tr                1    1    0    0    0    0
  301     Resid./Recr                  1    1    0    0    0    0
  302     Comm./Ind./Tr                1    1    0    0    0    0
  401     Resid./Recr                  1    1    0    0    0    0
  402     Comm./Ind./Tr                1    1    0    0    0    0
  501     Resid./Recr                  1    1    0    0    0    0
  END GEN-INFO

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  101  501    0    1    0    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (in)
  101            800   0.05796      0.05       0.1
  102            777   0.03985      0.05       0.1
  201            800   0.02881      0.05       0.1
  202            800   0.04844      0.05       0.1
  301            342   0.04255      0.05       0.1
  302            672   0.07298      0.05       0.1
  401            637   0.08572      0.05       0.1
  402            800   0.03151      0.05       0.1
  501            202    0.1825      0.05       0.1
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  101  501       40.       35.
```

```
  END IWAT-PARM3

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  101  501      0.01      0.01
  END IWAT-STATE1

  NQUALS
*** x -  xNQUAL
  101  501    1
  END NQUALS

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x      QUALID    QTID  QSD VPFW  QSO  VQO
  101  501   FECAL COLIFO    #    0    0    1    1
  END QUAL-PROPS

  QUAL-INPUT
***            SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                  ac.day
  101         0.00    0.00    0.00    0.00    0.10
  102         0.00    0.00    0.00    0.00    0.10
  201         0.00    0.00    0.00    0.00    0.10
  202         0.00    0.00    0.00    0.00    0.10
  301         0.00    0.00    0.00    0.00    0.10
  302         0.00    0.00    0.00    0.00    0.10
  401         0.00    0.00    0.00    0.00    0.10
  402         0.00    0.00    0.00    0.00    0.10
  501         0.00    0.00    0.00    0.00    0.10
  END QUAL-INPUT

  MON-ACCUM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     02E0802E0802E0802E0801E0801E0801E0801E0801E0801E0801E0802E08
  102     03E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E06
  201     31E0830E0828E0828E0827E0826E0825E0825E0825E0824E0825E0828E08
  202     06E0606E0606E0606E0606E0606E0606E0606E0606E0606E0606E0606E06
  301     04E0804E0804E0804E0804E0804E0803E0803E0803E0803E0803E0804E08
  302     03E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E06
  401     45E0844E0842E0841E0840E0839E0837E0837E0837E0836E0837E0841E08
  402     01E0601E0601E0601E0601E0601E0601E0601E0601E0601E0601E0601E06
  501     17E0816E0815E0815E0814E0814E0813E0813E0813E0813E0813E0815E08
  END MON-ACCUM

  MON-SQOLIM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     34E0833E0847E0876E0874E0872E0868E0868E0868E0840E0827E0830E08
  102     68E0668E0601E0802E0802E0802E0802E0802E0802E0801E0868E0668E06
  201     06E1006E1009E1014E1013E1013E1012E1012E1012E1007E1005E1006E10
  202     01E0801E0802E0803E0803E0803E0803E0803E0803E0802E0801E0801E08
  301     85E0882E0801E1002E1002E1002E1002E1002E1002E1098E0868E0876E08
  302     56E0656E0684E0601E0801E0801E0801E0801E0801E0884E0656E0656E06
  401     09E1009E1013E1021E1020E1019E1018E1018E1018E1011E1007E1008E10
  402     29E0629E0643E0672E0672E0672E0672E0672E0672E0643E0629E0629E06
  501     03E1003E1005E1007E1007E1007E1007E1007E1007E1004E1003E1003E10
  END MON-SQOLIM
END IMPLND
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APPENDIX D

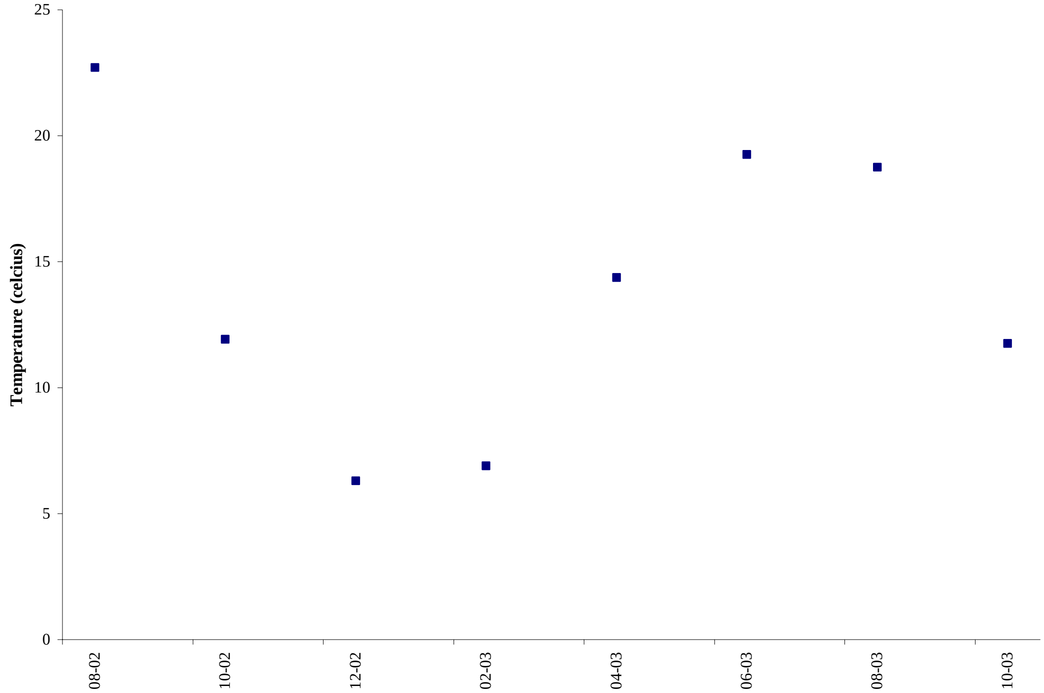

Figure D.1 Temperature measurements at 9-BCK000.74.

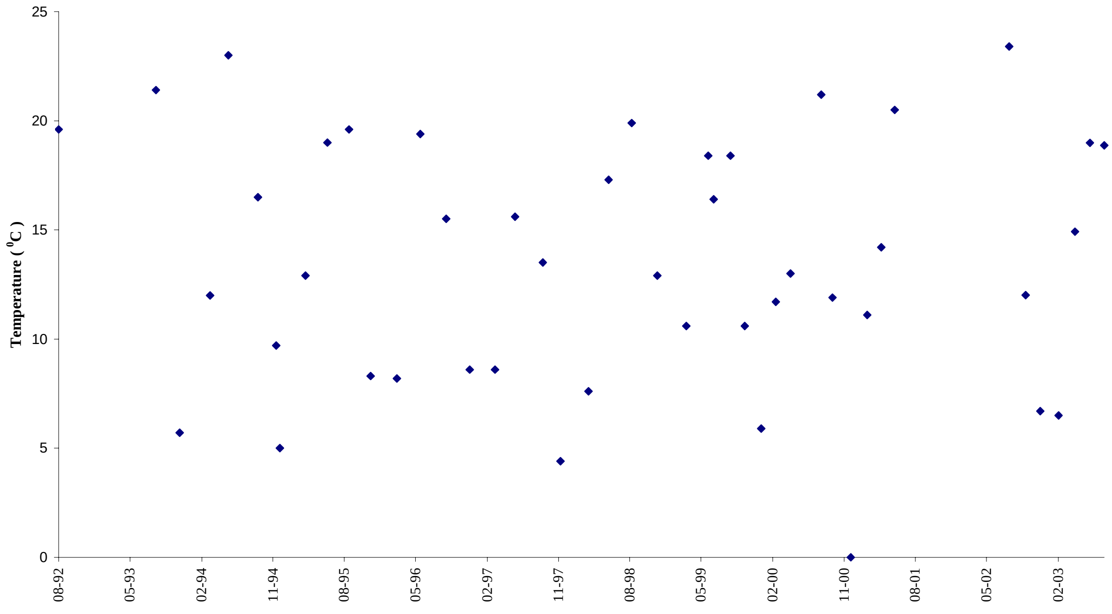

Figure D.2 Temperature measurements at 9-BCK009.47.

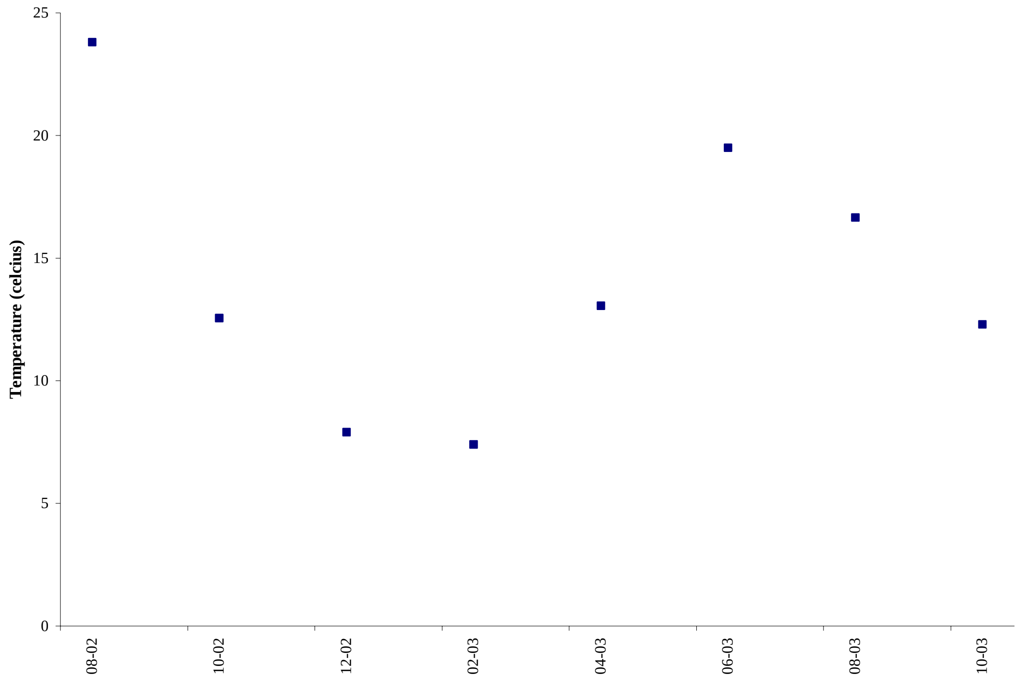

Figure D.3 Temperature measurements at 9-BCK015.98.

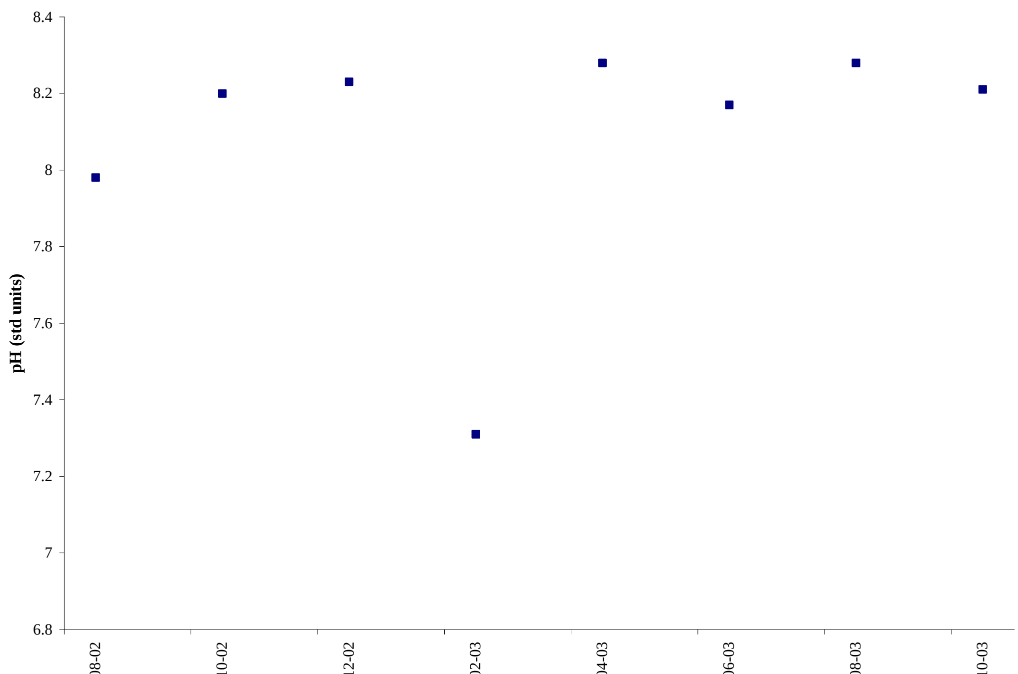

Figure D.4 pH measurements at 9-BCK000.74.

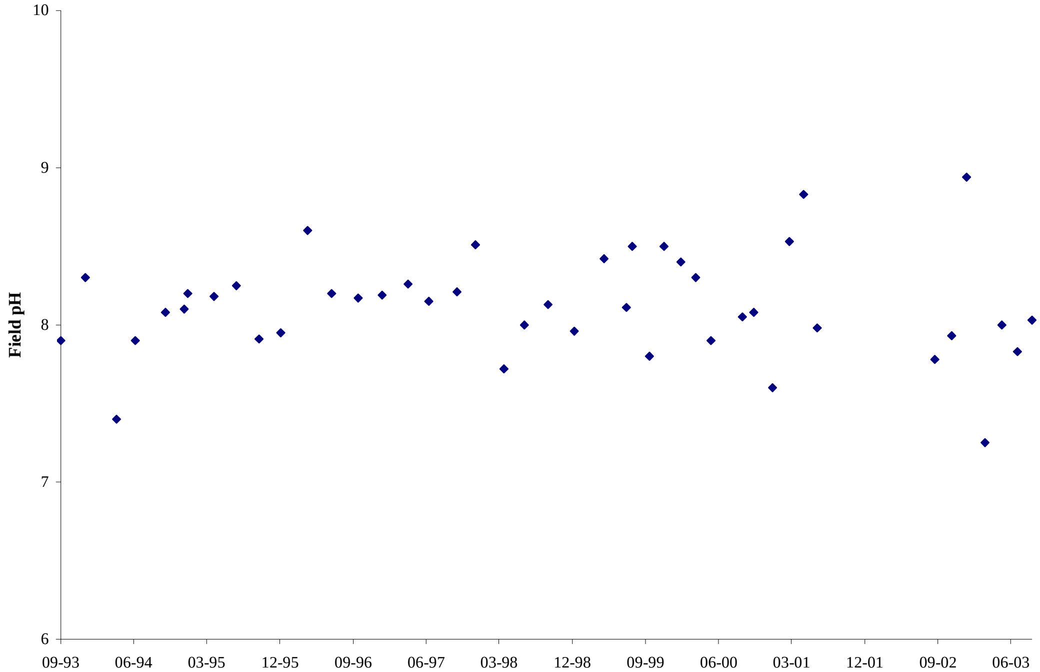

Figure D.5 pH measurements at 9-BCK009.47.

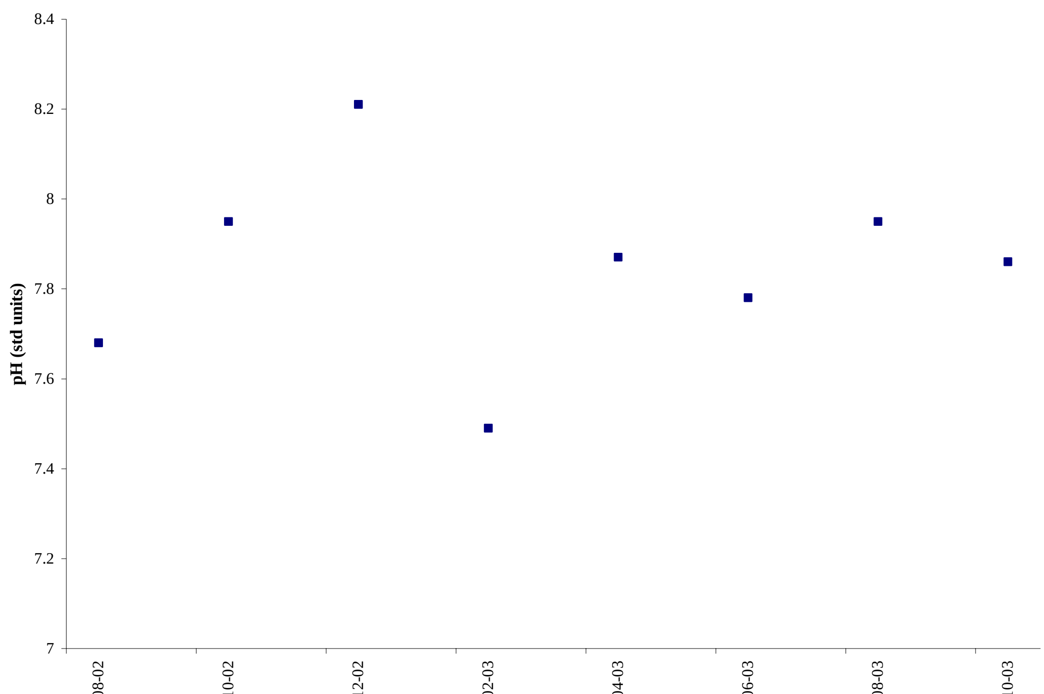

Figure D.6 pH measurements at 9-BCK015.98.

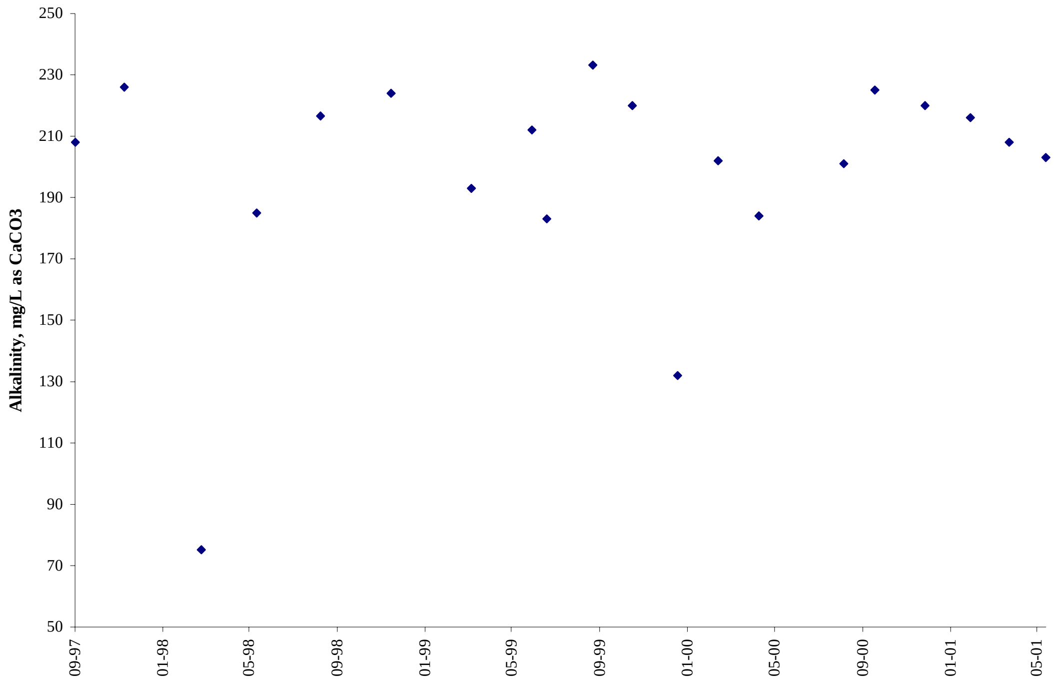

Figure D.7 Alkalinity concentrations at 9-BCK009.47.

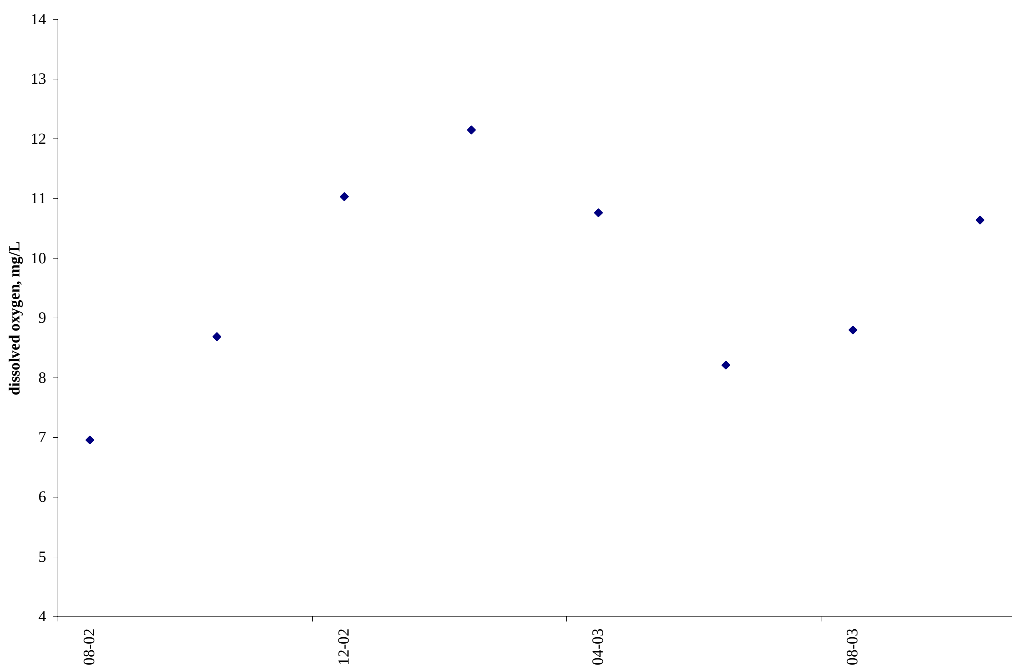

Figure D.8 Dissolved oxygen concentrations at 9-BCK000.74.

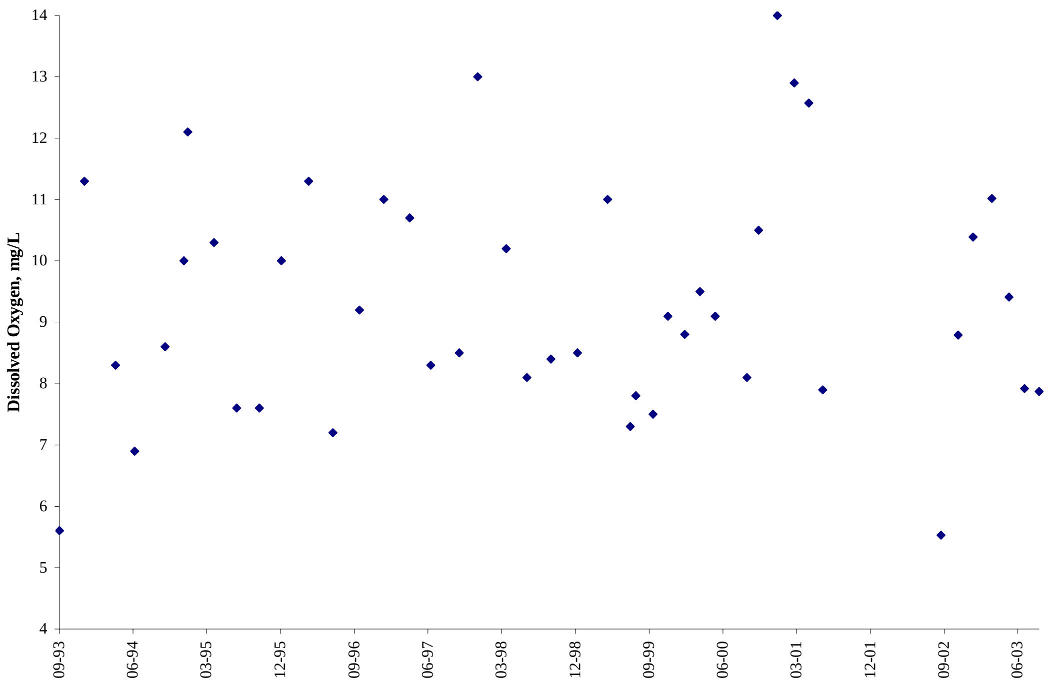

Figure D.9 Dissolved oxygen concentrations at 9-BCK009.47.

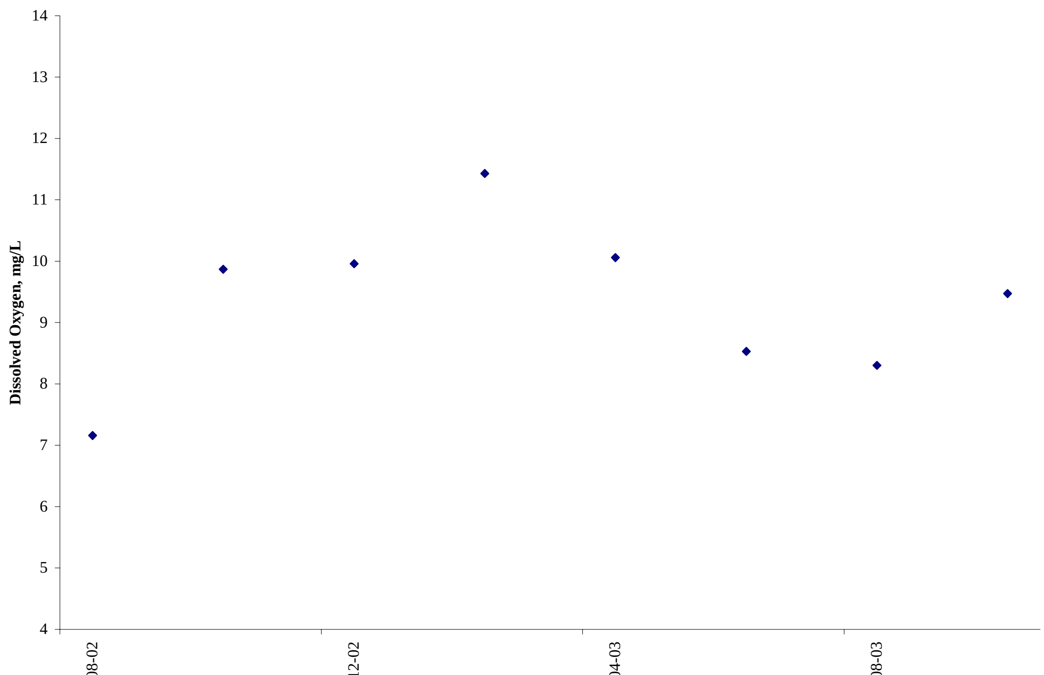

Figure D.10 Dissolved oxygen concentrations at 9-BCK015.98.

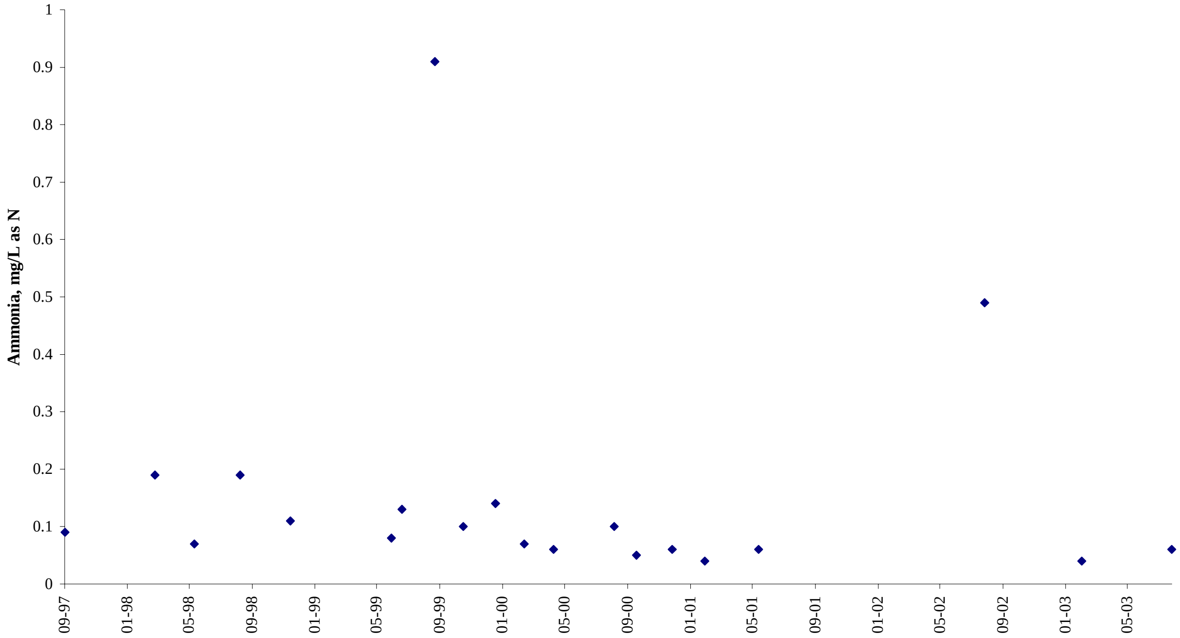

Figure D.11 Ammonia concentrations at 9-BCK009.47.

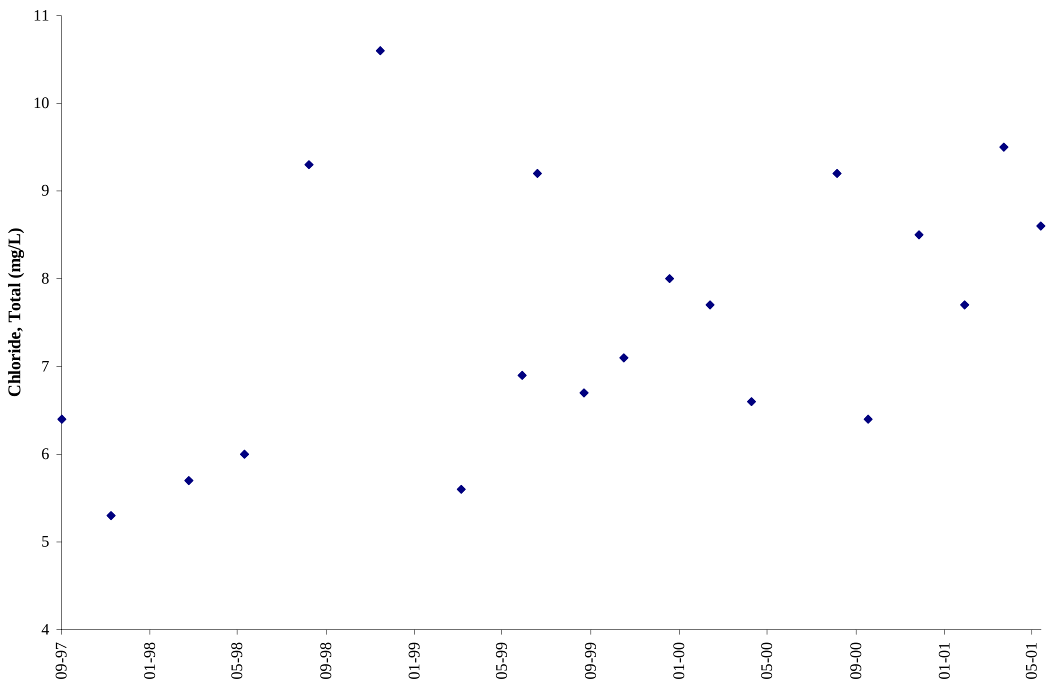

Figure D.12 Chloride concentrations at 9-BCK009.47.

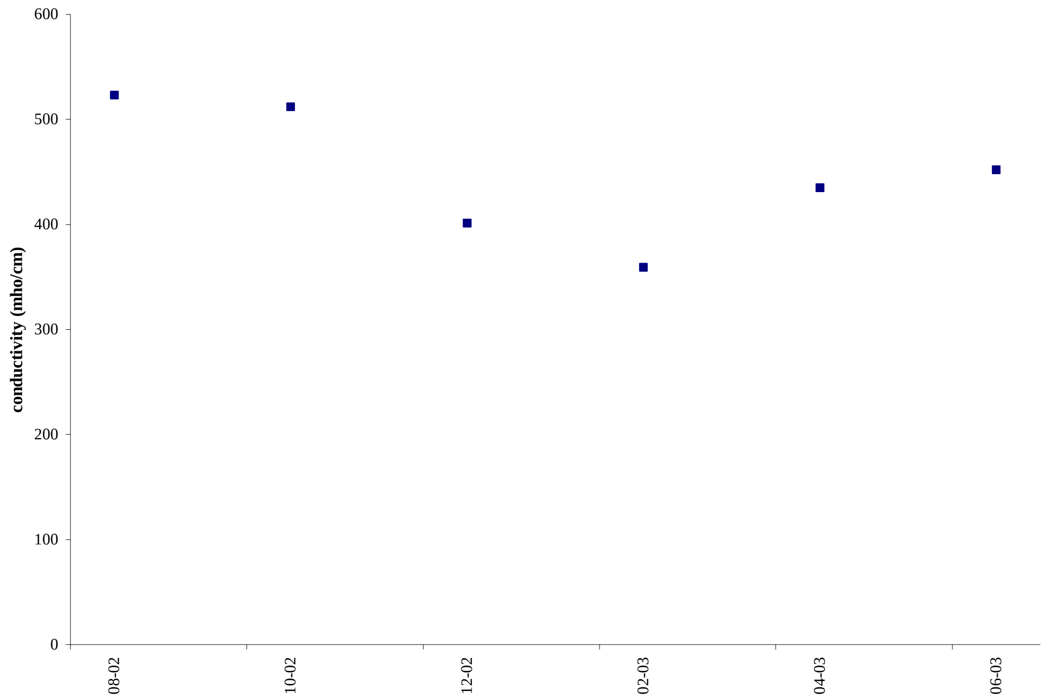

Figure D.13 Conductivity at 9-BCK000.74.

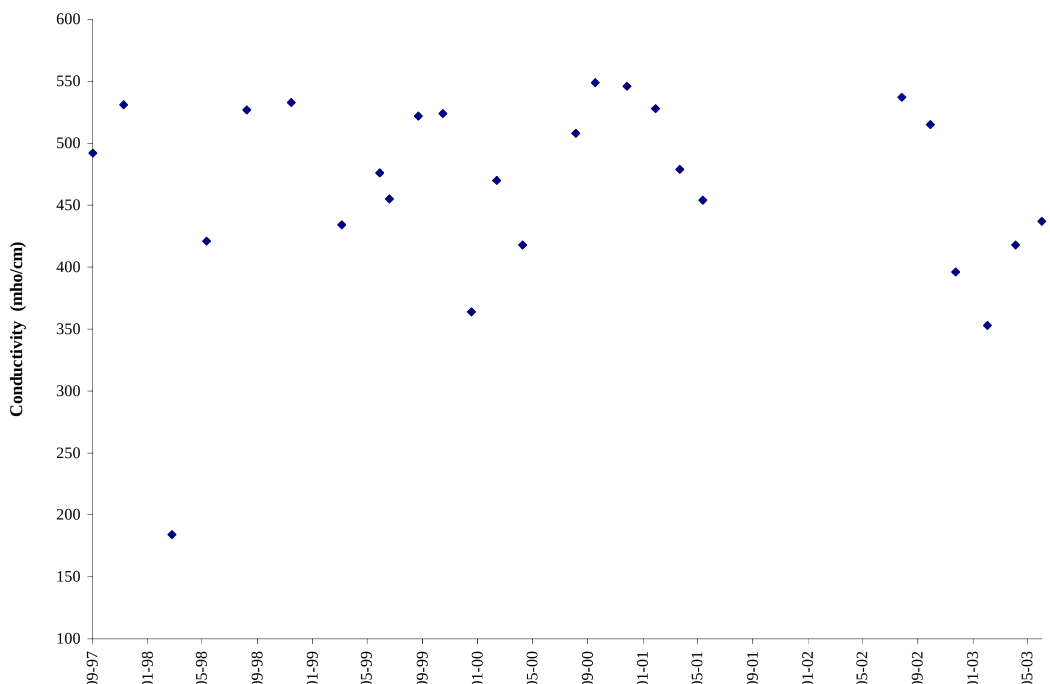

Figure D.14 Conductivity at 9-BCK009.47.

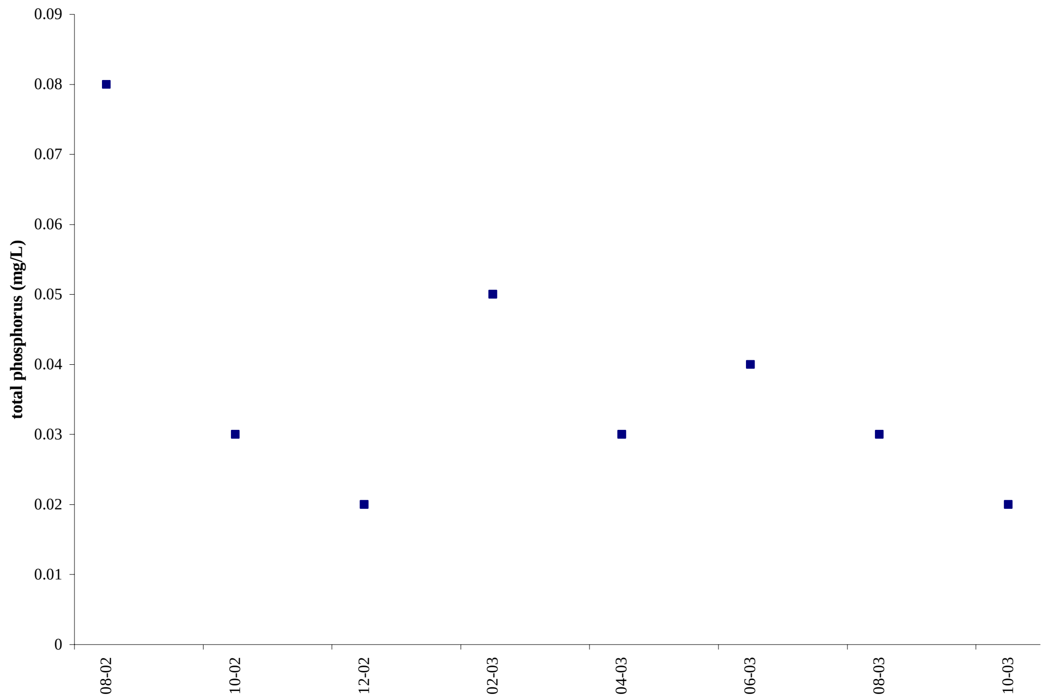

Figure D.15 Total phosphorus concentrations at 9-BCK000.74.

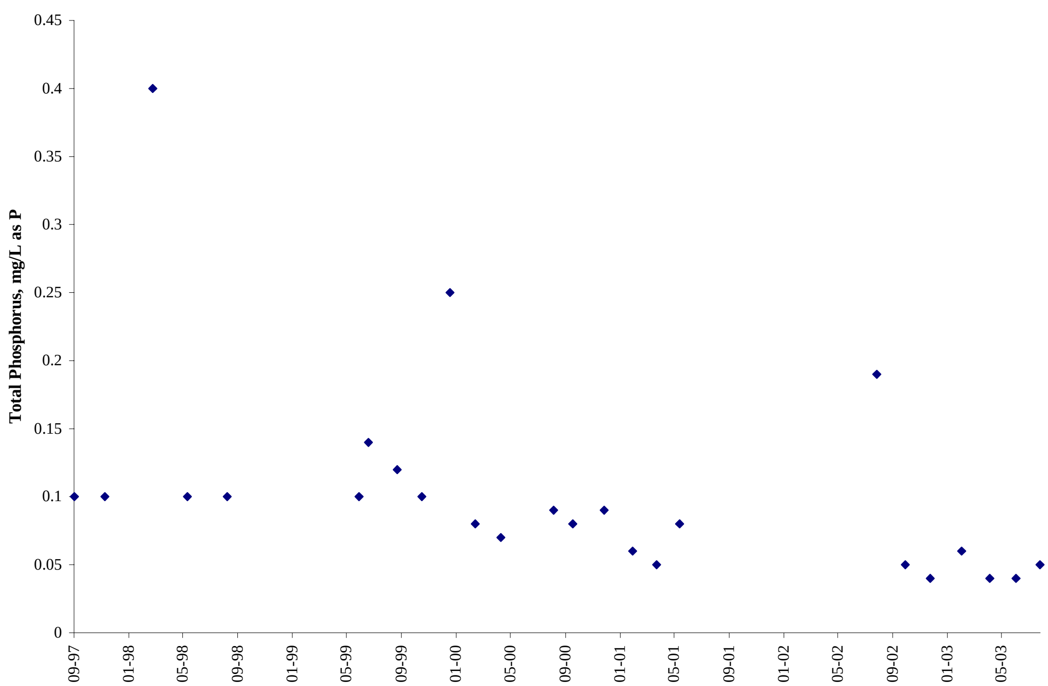

Figure D.16 Total phosphorus concentrations at 9-BCK009.47.

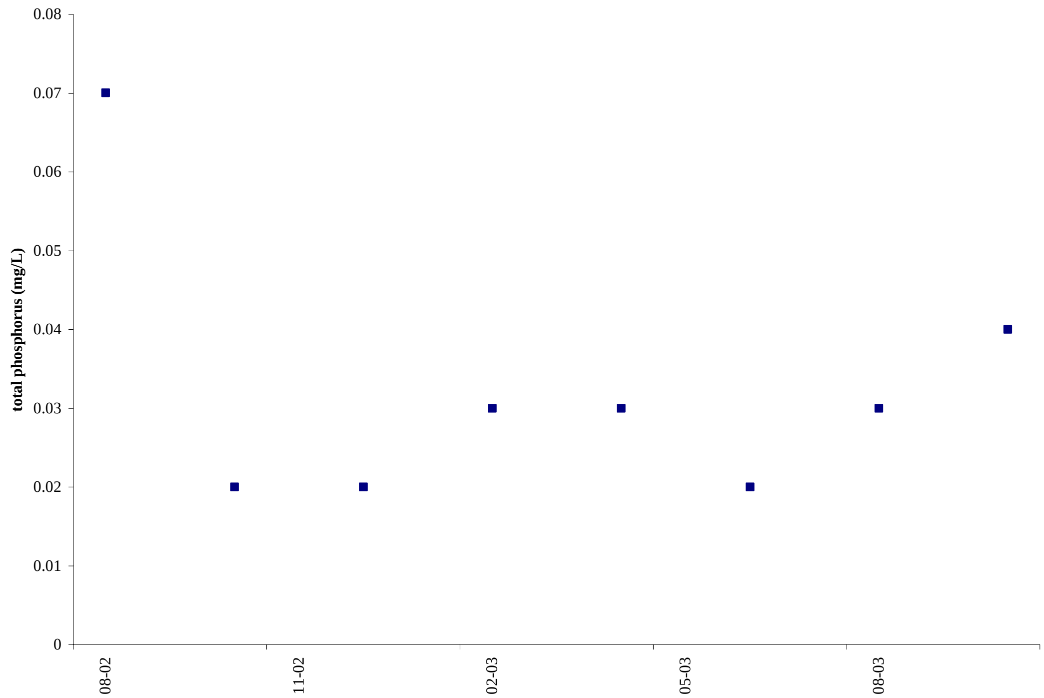

Figure D.17 Total phosphorus concentrations at 9-BCK015.98.

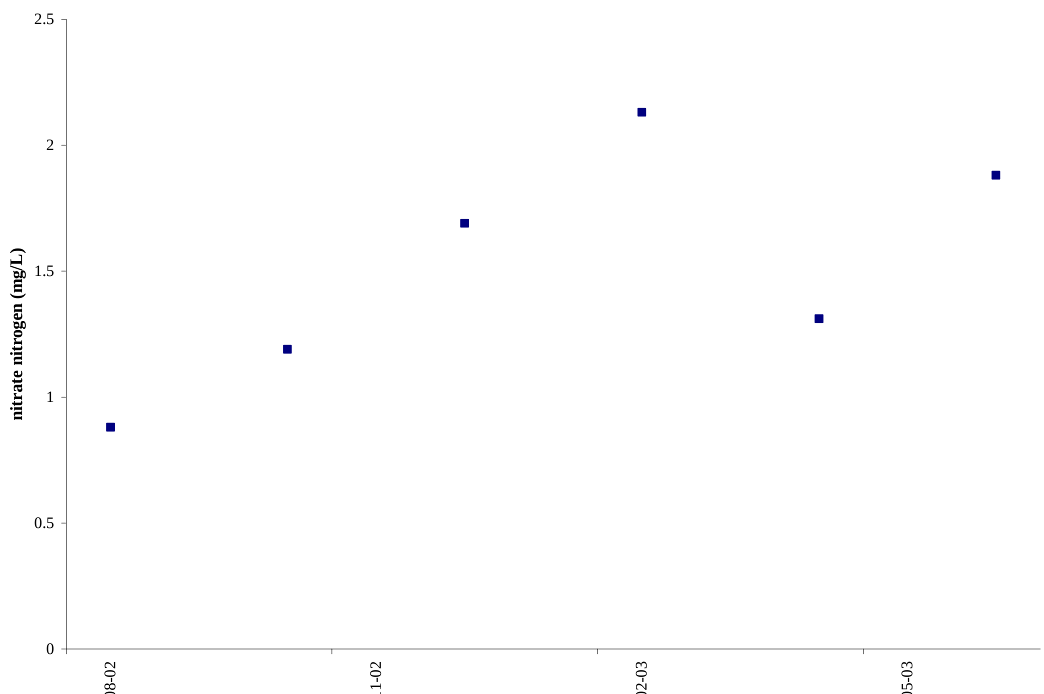

Figure D.18 Nitrate nitrogen concentrations at 9-BCK000.74.

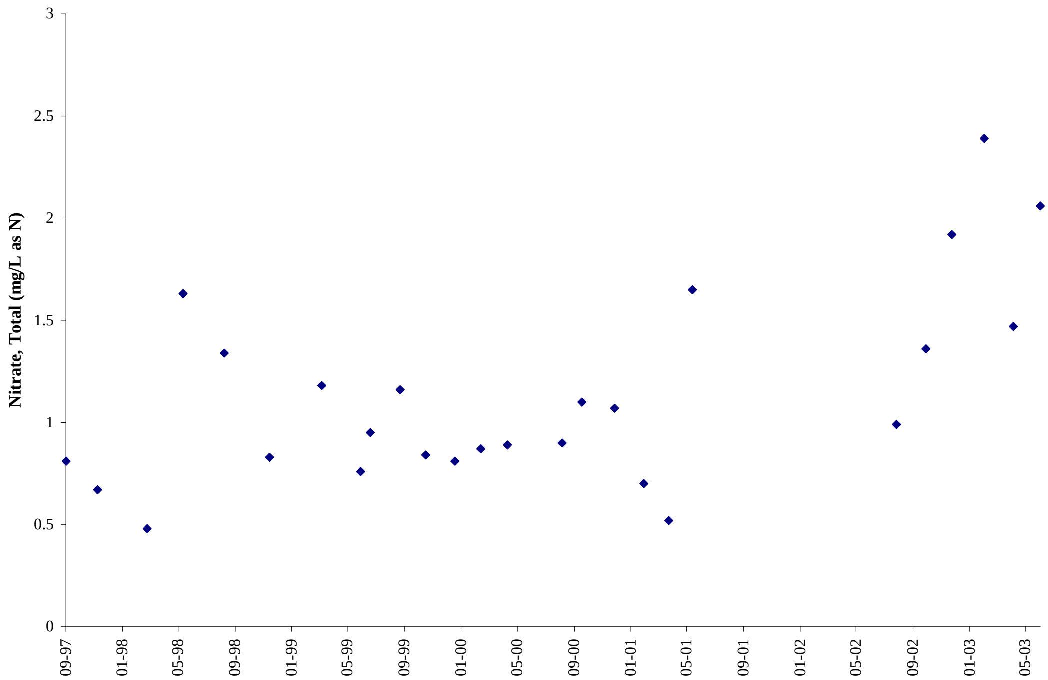

Figure D.19 Nitrate nitrogen concentrations at 9-BCK009.47.

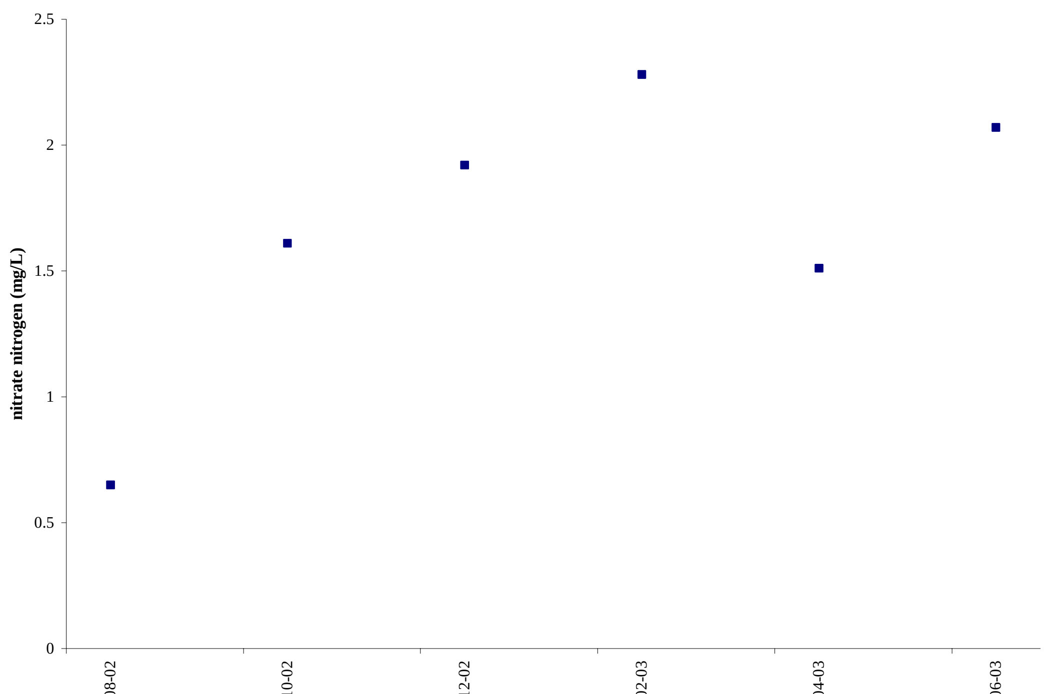

Figure D.20 Nitrate nitrogen concentrations at 9-BCK015.98.

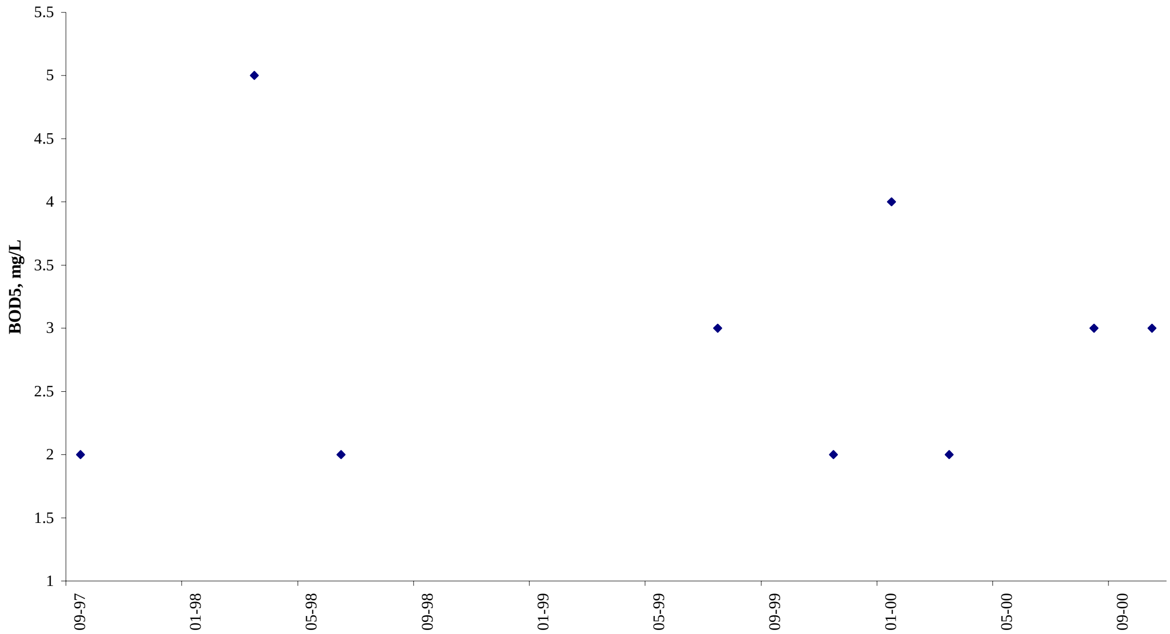

Figure D.21 Biochemical oxygen demand concentrations at 9-BCK009.47.

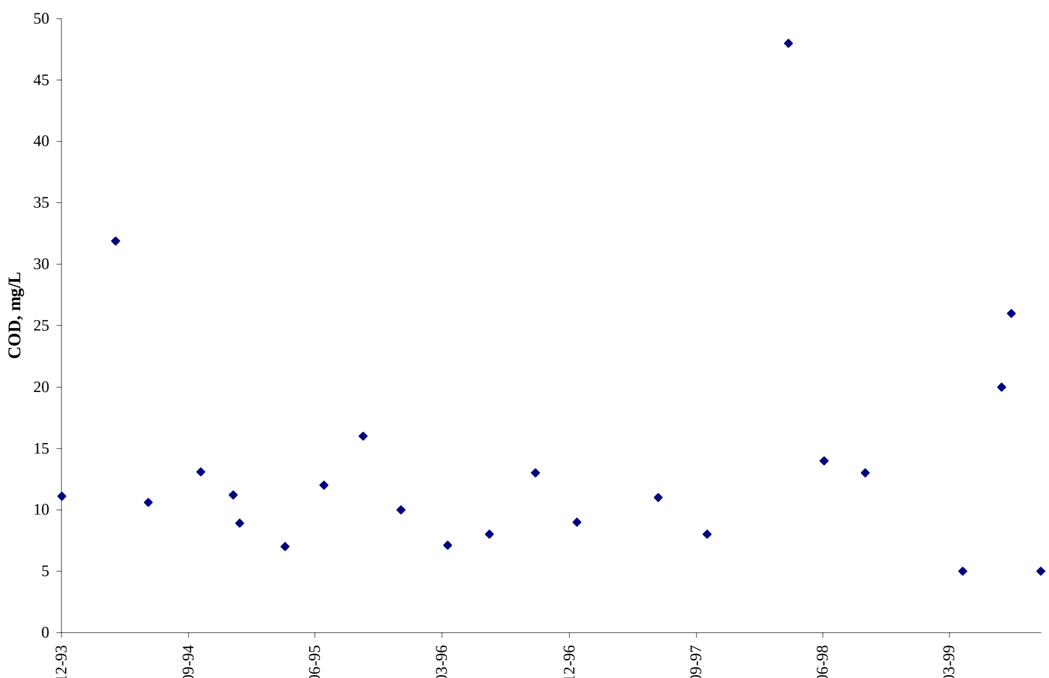

Figure D.22 Chemical oxygen demand concentrations at 9-BCK009.47.

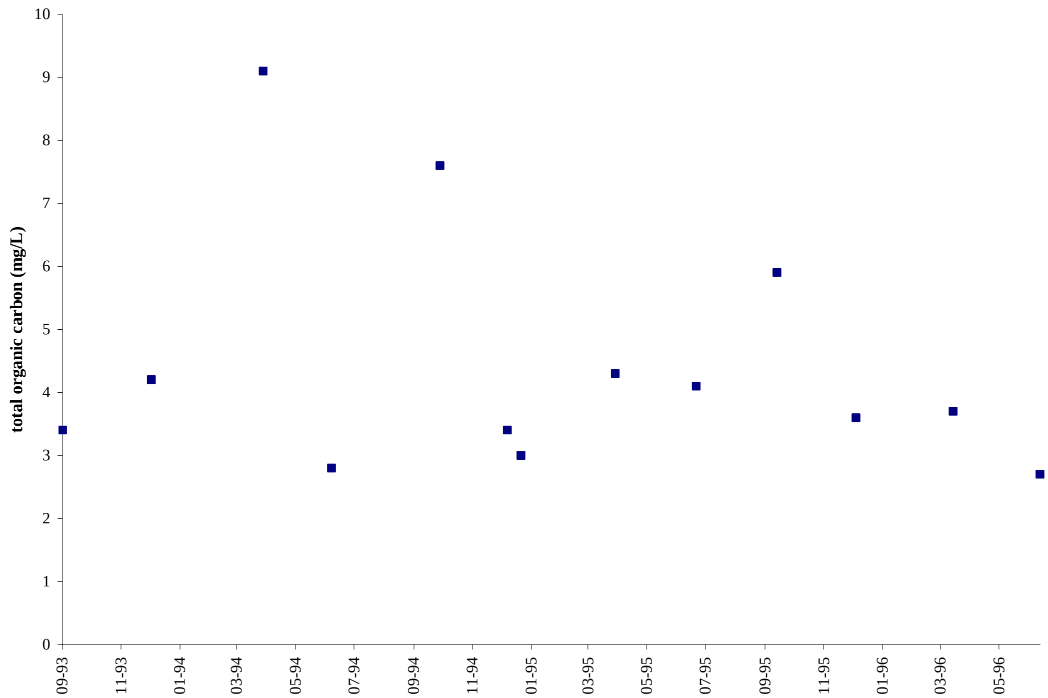

Figure D.23 Total organic carbon concentrations at 9-BCK000.74.

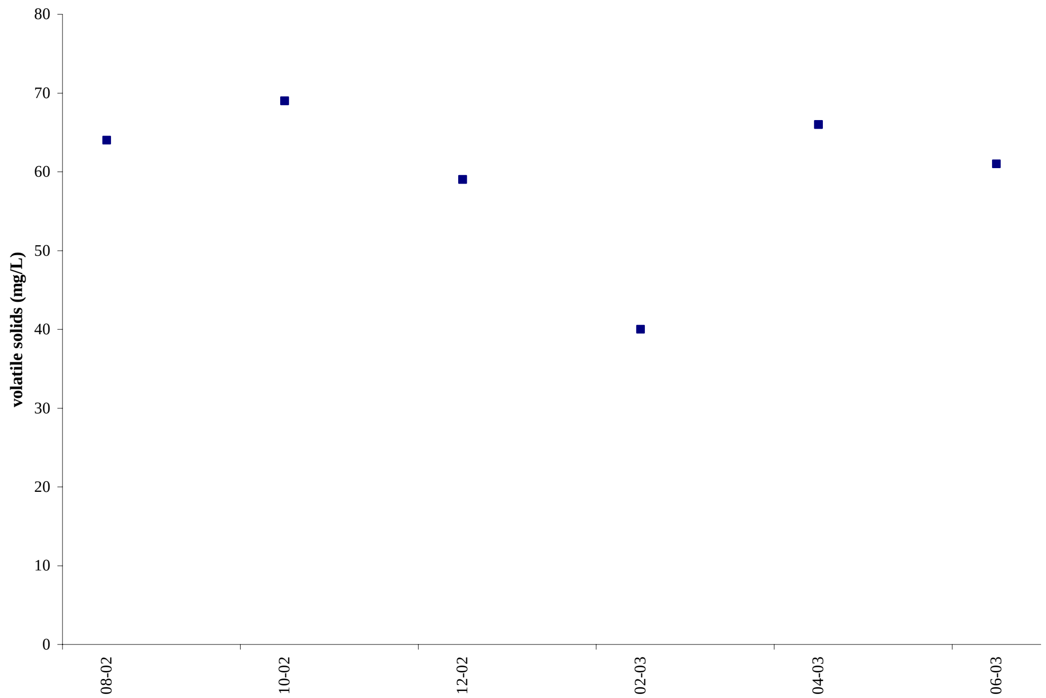

Figure D.24 Volatile solids concentrations at 9-BCK000.74.

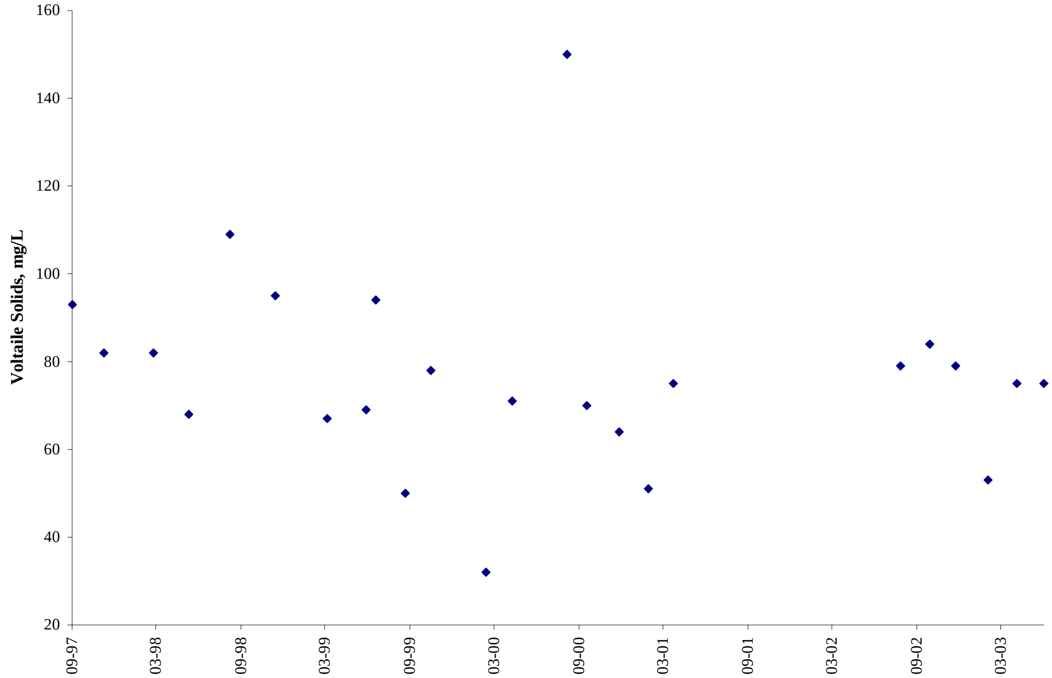

Figure D.25 Volatile solids concentrations at 9-BCK009.47.

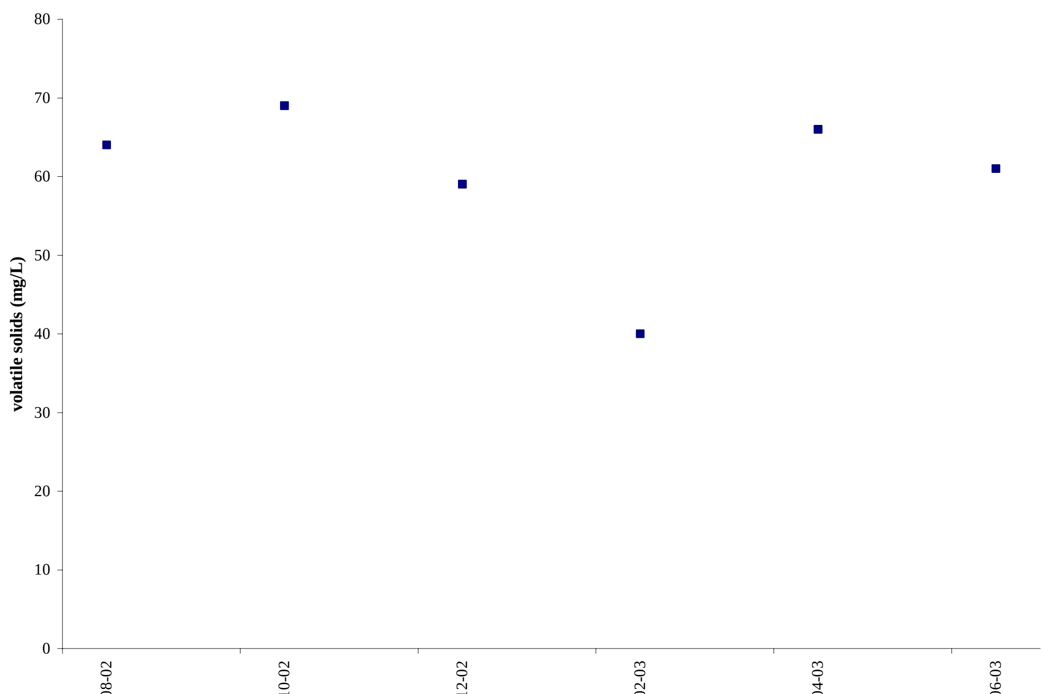

Figure D.26 Volatile solids concentrations at 9-BCK015.98.

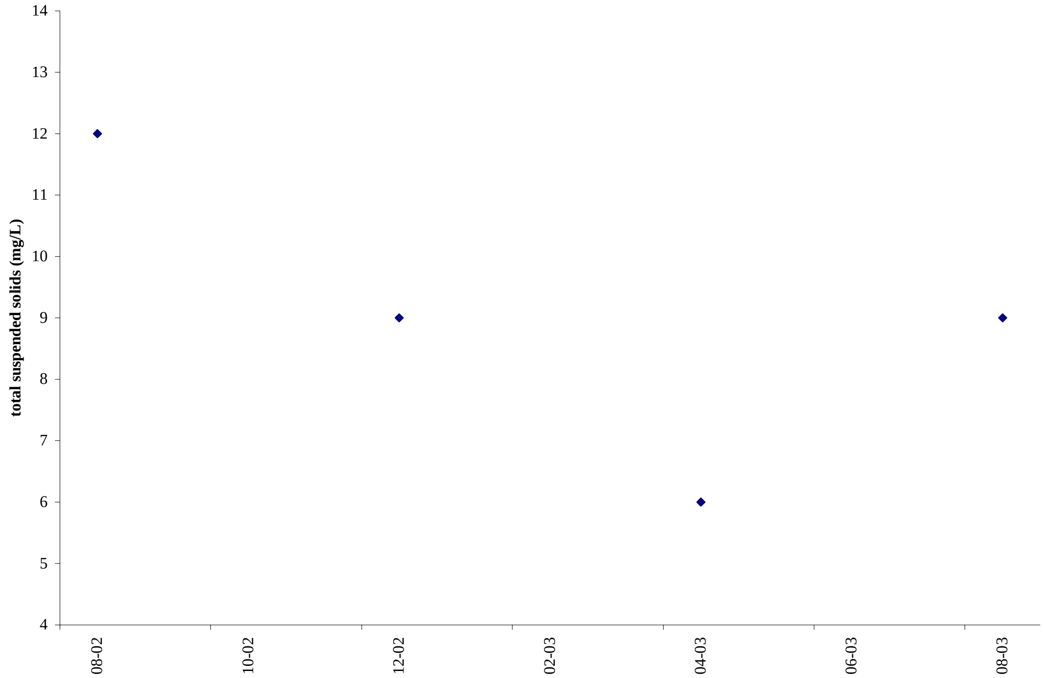

Figure D.27 Total suspended solids concentrations at 9-BCK000.74.

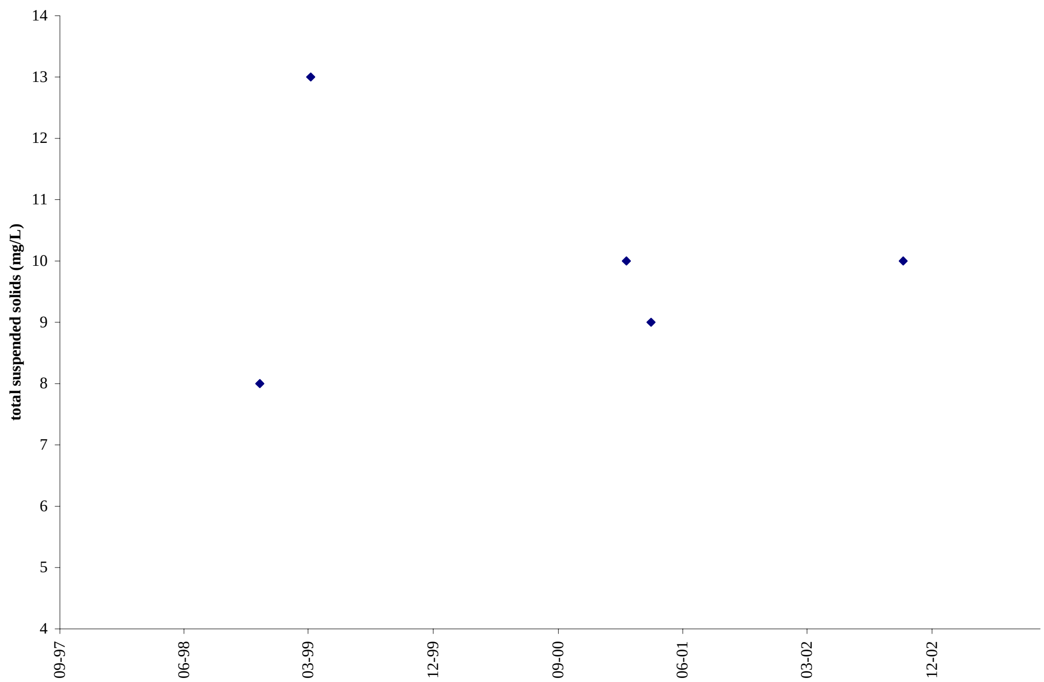

Figure D.28 Total suspended solids concentrations at 9-BCK009.47.

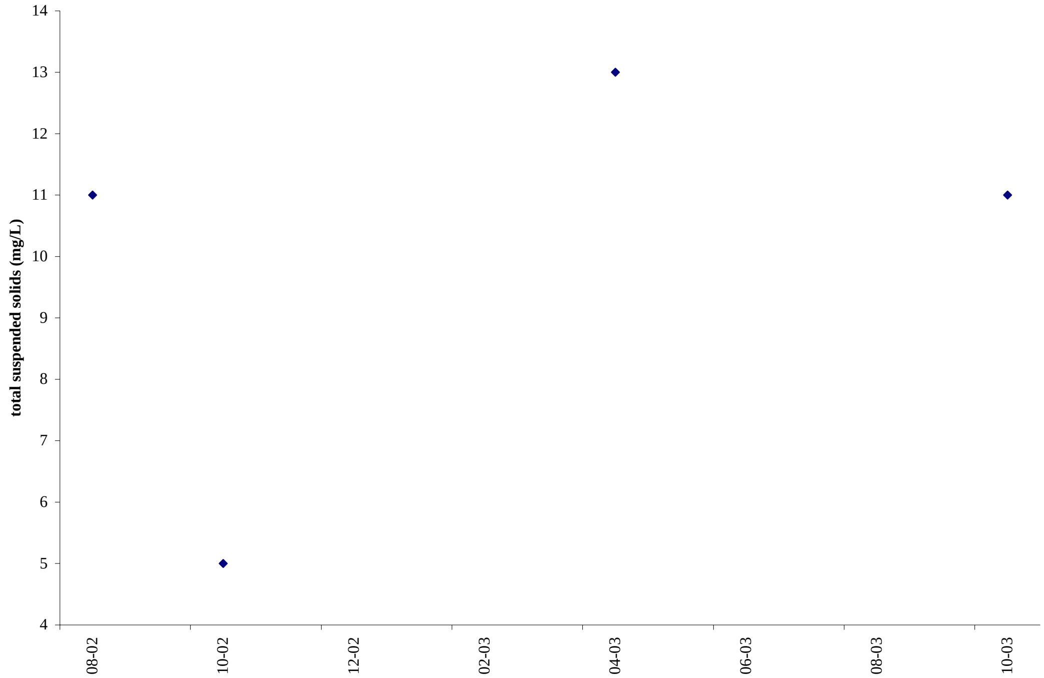

Figure D.29 Total suspended solids concentrations at 9-BCK015.98.

APPENDIX E

Table E.1 Average annual E. coli loads (cfu/year) modeled for the Back Creek watershed impairment after TMDL allocation with permitted point source loads increased five times.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Back Creek (FC)	1.31E+10	1.02E+13	*Implicit*	1.02E+13
VAG402033[1]	*4.35E+09*			
VAG402086[1]	*8.70E+09*			

[1] General permits – single family home.